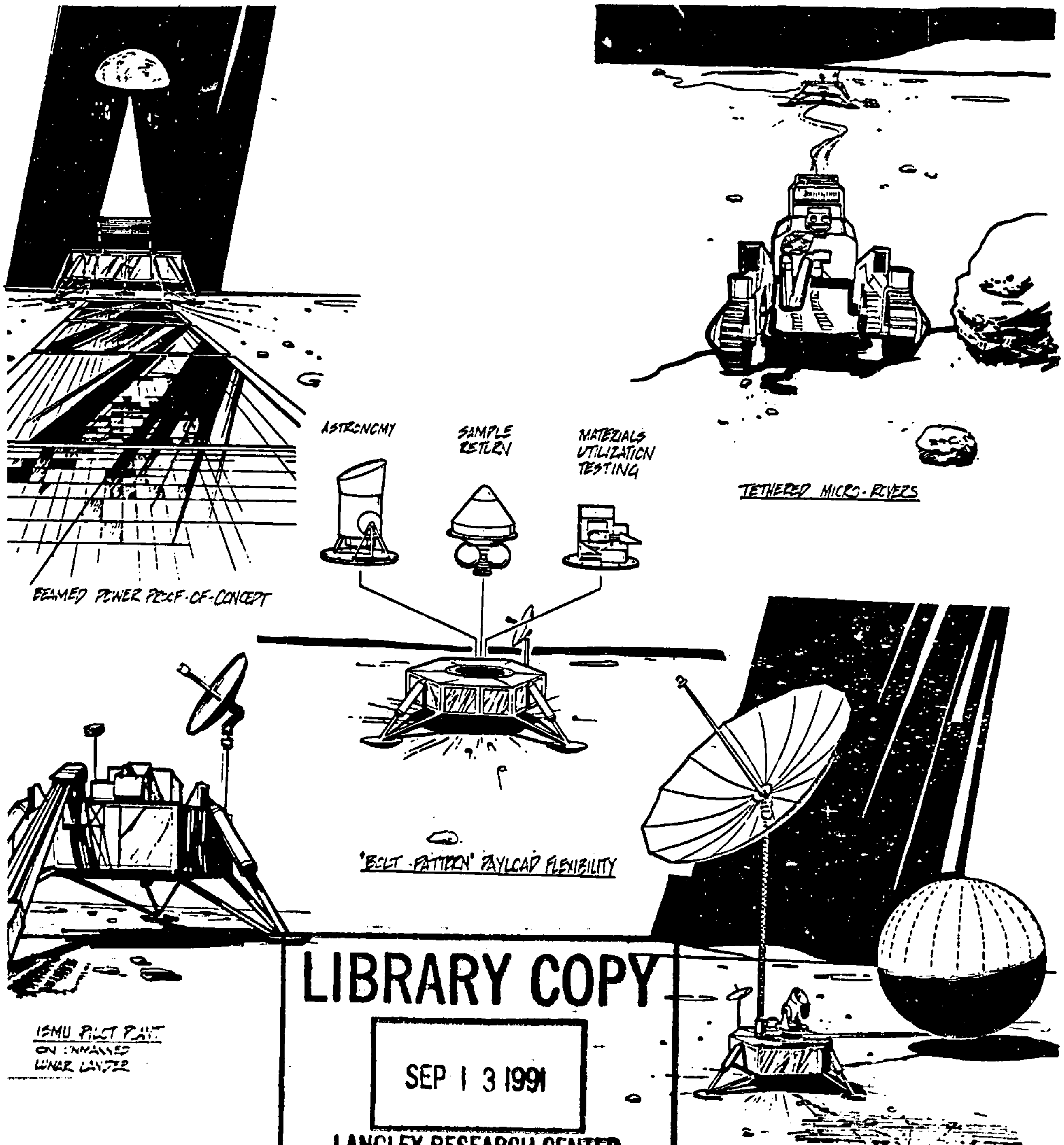
NASA-TM-109865

N-169903

NASA

Proceedings of the
Workshop on the Concept of a Common Lunar Lander
NASA /JSC July 1-2, 1991



(NASA-TM-109865) PROCEEDINGS OF THE WORKSHOP ON THE CONCEPT OF A COMMON LUNAR LANDER (NASA. Johnson Space Center) 247 p

N94-72124

Unclas

29/91 0015699

INTRODUCTION

Common Lunar Lander Workshop Proceedings

Introduction

This package contains the collected proceedings of the Workshop on the Concept of a Common Lunar Lander, held July 1 and 2 at the NASA Johnson Space Center. These proceedings are representative of the workshop but are not comprehensive. The purpose of this mailing is to provide a set of materials to those unable to attend, and to inform the community of the current status of the study as well as future plans.

The study has been approved by the JSC Center director Aaron Cohen, and will involve an in-house study team tasked to produce a strawman program plan and design concept. The design concept will be presented to the center director on September 17, shortly thereafter a set of payload design guidelines to assist potential payload designers will be available. This payload designer's handbook will clearly identify the lander's performance, capabilities, constraints, envelopes, and interfaces. With this information, payload developer's can provide a critical assessment of the lander, and can determine the utility of such a vehicle in achieving their goals. In mid-October a program plan will be completed which will include program options considered, evaluation criteria, and recommendations to the agency on the best strategies for procurement, program management, and resource and facility utilization, it will also contain cost and schedule estimates.

Workshop Assessment

Despite the short notice, the July 4 holiday week, the conflicts with several other important conferences, and the lack of any travel funds, over 140 representatives of industry, academia and the Government attended. At the workshop a market analysis was performed, and technical and programmatic issues were identified and addressed. A strong consensus emerged that the concept had great potential and that a broad base of support exists for a Common Lunar Lander program.

Organization

After some introductory remarks, the workshop was divided into parallel working sessions. The agenda is enclosed following this summary; the topics and speakers are as follows.

Lunar Surface Science

Dr. Paul Spudis lead the discussion by pointing out some elements in a geoscience strategy: 1) global reconnaissance, 2) site reconnaissance, and 3) site field science. In order to accomplish global reconnaissance, a series of geophysical stations could be emplaced on the surface containing a variety of scientific instruments, such as, a seismometer, a heat flow probe, an XRF, etc. By the end of the discussion, it had been suggested that these geophysical instruments could become a standard payload package for the lunar lander, forming a network with each successful landing. This network would require landing on the far side of the moon, thus allowing scientists an opportunity to identify the interior of the moon.

Lunar atmospheric studies were also discussed as possible lander payloads. The lunar atmosphere, albeit small, contains gases ejected from the surface and captured from the solar wind. Each time a spacecraft landed on the surface, chemicals from its rocket exhaust were added to the atmosphere upsetting the delicate balance. Since twenty years have passed since the last moon landing, the lunar atmosphere has probably returned to its original state (i.e. before surface landings). It was stressed that it is important to perform experiments on the atmosphere early in the program because of contamination of subsequent landings.

The possibilities of using rovers or micro-rovers was also addressed. There are over 90 sites deemed by scientists as places were exploration would reveal more about the composition of the moon and the objects that have impacted it over its history. These rovers would be able to move about taking data or collecting samples to be returned to earth. An earth-return stage would be required as part of the payload, and could simply be a direct return Apollo-like capsule. While these rovers could collect samples for study, they might also perform in-situ analyses to determine composition.

Lunar Astronomy

The lunar astronomy session was chaired by Dr. Jack Burns. Among the topics of discussion was the advantages of doing astronomy from the moon: 1) low gravity, 2) low density atmosphere, 3) seismic stability, 4) low levels of radio noise & light, and 5) natural cryogenic environment. There were, however, concerns with the lunar environment: 1) cosmic radiation, 2) micrometeoroids, 3) thermal variations, and 4) cost. Other items such as locations, such as the equator, near-side, far-side, and poles, were also discussed.

Rationale for devising possible payloads was simplicity using current technology. From there an evolution to advanced telescopes could be made. A first astronomy payload could be a lunar transit telescope which contains nearly no moving parts. The mirror does continuous imaging of a small strip of the sky. This telescope also has a continuously updating CCD that can withstand a very low light level.

Another payload could be a one-meter class optical telescope because of its small weight and low cost. A series of these telescopes would be able to do surveys of certain objects and address issues that the Hubble Space Telescope is incapable of addressing. Or, since a spare Hubble mirror exists, use it to build a Hubble-like telescope on the surface of the moon. This use of the spare mirror could be used as a test bed for more complicated instruments. There was a question of the weight of the mirror and delivery capability of the lander.

Other single astronomy payloads included an ultraviolet telescope, a polar infra-red telescope, a low frequency radio telescope, and moon-earth radar. The low frequency radio telescope is simply a ten meter dipole antenna that could unfold upon landing and begin operations. A network of these dipoles could be organized into a networking array once an adequate number of antennas are delivered by the lander.

In-Space Materials Utilizations

Dr. Tom Sullivan lead the session with suggestion for near- and mid- term experiments that could be performed once delivered to the surface of the moon. In the near-term, topics like prospecting, resource mapping, sample return, and system survivability were discussed. Furthermore, pilot plants which would be able to process and analyze regolith could be delivered as payloads to measure radiation protection of the soil, volatiles release, etc. The mid-term experiments would include rovers for regional analysis and "rendezvous and dumping" tests. Also tests on mining equipment, pneumatic mining techniques, and processing soil volatiles could provide materials researchers the necessary data to design strategies for mining the moon.

Certain engineering experiments were addressed, such as an investigation of soil digging/moving and a determination of the effect and duration of the lunar environment on system mechanisms. Other proposed experiments were specific to processing demonstration/validation. There is a need to demonstrate a working system for extracting oxygen before humans are sent back to the moon to stay. Along the same line of thinking, there would be a need to demonstrate a working system for extracting volatiles like hydrogen, nitrogen, and helium from the soil. Lastly, there also must be a demonstration of a system to produce construction materials such as sintered bricks, metal ingots, and glass products. With all of these demonstration experiments, the lander could serve the function of delivering the test bed for new technologies in the are of materials utilization, long before the first humans return.

Engineering and Technology

David Weaver lead the discussion of engineering and technology payloads which could utilize the lander as a delivery service to prove technological concepts that could be used for other manned or unmanned programs. The challenge of the common lunar lander program is to make it an integral part of the front end of science and engineering and technology areas.

Waypoints of the Synthesis Group were presented and shown how the lander could help accomplish them. For lunar exploration, the lander could emplace geophysical network stations and deliver surface rovers to collect samples. Certain precursor activities in the areas of ISMU and technology could be carried to the surface, thus allowing researchers to examine ways humans may adequately inhabit the moon.

As technology demonstration cargos, autonomous landing and hazard avoidance systems were discussed. These payloads would be vital for manned missions to unknown locales or the first landing on Mars. With hazard detection, the spacecraft would "see" obstacles and maneuver around them allowing the chance for a greater success. An autonomous approach and landing package currently is being used for cruise missile technology. The missiles use image processing consisting of GPS, inertia guidance, and data points mapped on the ground. The target is characterized and the craft recognizes it with checkpoint fixing. A demonstrator package could be developed as a payload and tested for use on future manned or unmanned missions.

Some comments that were added during the session were: 1) stick with the "bolt-pattern" and then determine what to fly, 2) commit to an end-to end testing of payloads and lander, 3) perform a Quality Function Definition (define what the customer wants), and 4) assume the lander provides little to no payload support other than a soft landing. The constraint of the program seems to be date and cost.

Lander Design

The lander design section was chaired by Steve Bailey and concentrated on systems of the lander itself such as power, propulsion, etc. Autonomous landing of the vehicle was discussed to some degree. A "man-in-the-loop" landing scheme was not ruled out, however, this looked costly at first glance. Questions of landing accuracy and general areas on the moon were presented. The accuracy of the lander would be dependant upon the specific payload that it was delivering. A rough survey showed that most of the payloads did not have a critical need for landing accuracy.

Radioisotope power systems were presented for use in the lander design. It was shown that these power systems are highly reliable and have variable lives and power levels according to mission guidelines. Currently, the U.S. supply of Plutonium-238 has been reserved for the Craf/Cassini missions. There is an approximately three year wait for production of new Pu-238 which means that RTGs would probably be a more ideal component later in the program. Furthermore, the cost of a single power is considerable, and ways of reducing unit costs such as a "modular" RTG program must be addressed.

Two types of rocket engines were discussed by TRW and Aerojet. The TRW company maintains a strong heritage with lunar programs, it developed the Apollo-LEM descent engine. It was suggested that the variable thrust engine from the defunct OMV project be used to propel the lander to the moon and perform the descent maneuver. A cluster of four of these engines would accomplish the task of delivering approximately 200 kg of payload to the moon's surface. This engine has been developed and taken to a hot fire on a test stand. The Advanced Liquid Axial Stage by Aerojet was also presented as part of the Brilliant Pebbles project. These engines could be clustered to operate in a single stage and double stage mode, whichever need arises. This engine as well had been hot fired on a test stand.

Programmatics

Kelly Cyr headed the programmatics session which discussed managerial approaches for the lander project. The concept of the lander is small, cheap, simple, and quick. Conclusions from this session were to have a short program. The longer a program is extended, more money is required to keep it operating. Furthermore, there should be a small project staff which can define the requirements and stick to them only to relax them if necessary.

Introduce a new way of doing business. Use contractor methods of reporting progress which would eliminate paperwork, rather than using NASA methods of reporting. Also, maintain a single interface with external working groups. Problems can usually be resolved in a more convenient fashion if there is a single person involved. In order to keep the cost of the program down, use "off-the-shelf" or proven technology. By using hardware already developed, development costs will have been erased which would lead to a faster paced program.

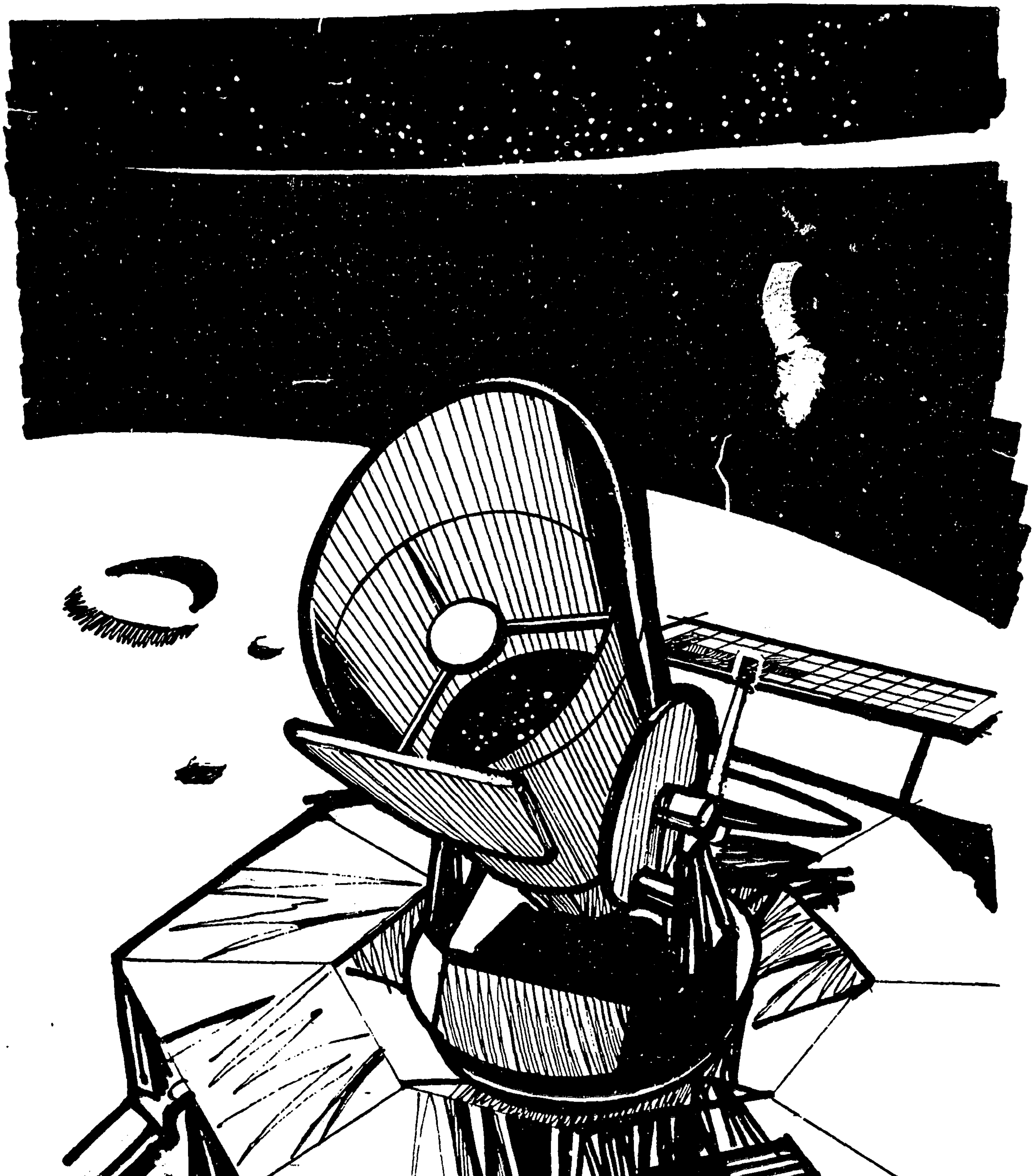
Workshop Synthesis

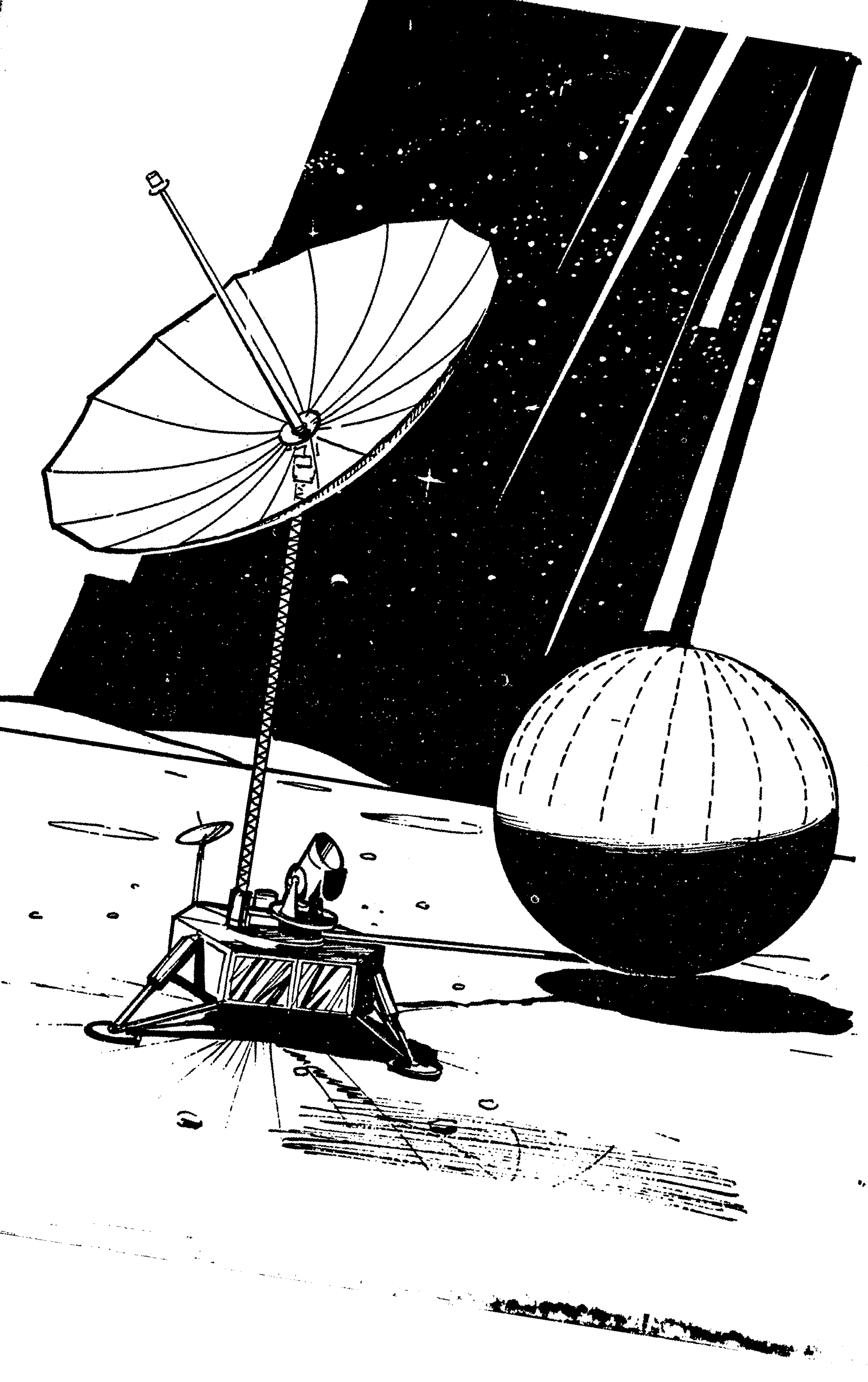
A general discussion of the lunar lander concept ensued with the addition of types of launch vehicles available for use. Representatives from General Dynamics and McDonnell Douglas each presented information on their respective launch vehicles, the Atlas and Delta II. Both launch systems appear to be candidates for the launching the lander and payload to low earth orbit and beyond. The Atlas family has a strong heritage with robotic lunar spacecraft due to the Surveyor series. An Atlas IIA / Star 48B would be capable of injecting a total weight of about 2100 kg were the Atlas IIAS / Star 48B could boost to the moon about 2500 kg. A three-stage Delta (7925) would be used for lunar missions and is capable of inserting about 1324 kg into trans-lunar orbit. Payload fairing sizes vary to allow a larger or smaller payload envelope as desired.

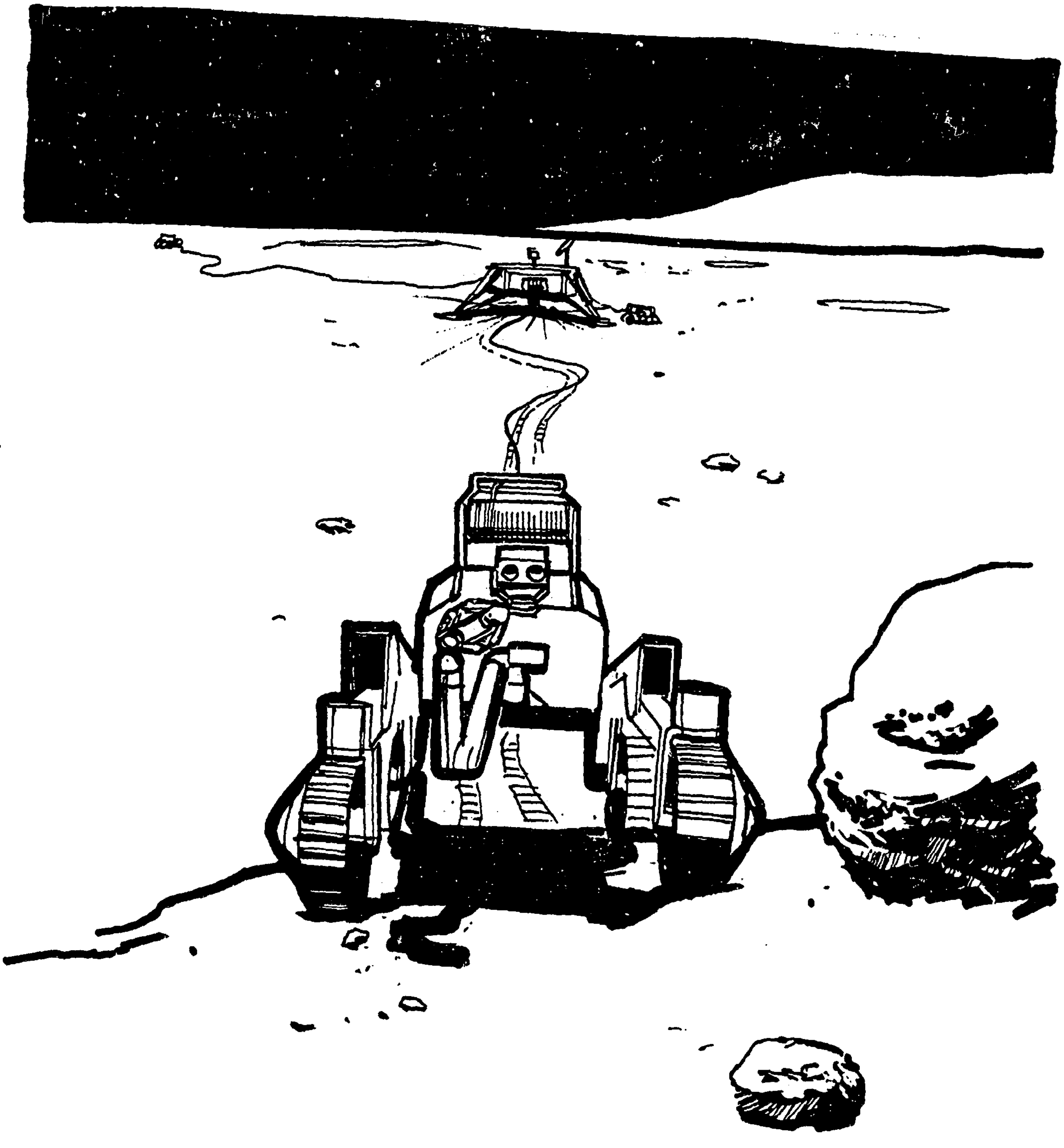
Other program aspects such as salability to Congress, prospects for international cooperation, and ties to US leadership, education, and technological competitiveness were discussed. A particularly strong potential of the Common Lunar Lander program would be to provide university experimenters access to a planetary surface inside their academic lifetimes, because of the proximity and frequent launch windows available with the Moon. Mars with its 26 month interval launch windows and one year trip times makes university participation problematic. The need for ties to primary education were also discussed, with some "hands-on" ideas presented.

Name	Organization	Address/Mail Code	Copies of Pres.? (Y/N)
Bret Drake	NASA/JSC/LMEPO	XM	N
Manuel I. Cruz	TRW	Redondo Beach, CA	Y
Ed Jones	General Dynamics	P.O. Box 85990, San Diego, CA 92186-5990 MZ-24-8710	Y
Thomas Starchville	NASA/JSC/HRSO	IE3	Y
Terry Gamber	Martin Marietta	M.S. DC 8082, P.O. Box 179 Denver, CO 80123	Y
Ron Wood	MDSSC-Houston	MDC-A2MI	Y
Donald Ryan	LMSC	1111 Lockheed Way, Bldg. 579 Orgn. 6N-29, Sunnyvale, CA	Y
Vince Doaan	MDSSC-Houston	MDCA 2BJ	Y
Steve Sponaugle	MDSSC-Houston	MDCA2EC	Y
Bill Schneider	CSC	4610 Powder Mill Rd, Calverton, MD 20705	Y
Harry Johnson	Grumman	12000 Aerospace Ave., Houston, TX 77034	Y
Bret Engelhemier	CSR-UT-Austin	402 WRW, Univ. of Texas, Austin, TX 78712-1085	Y
Darrel Monroe	UT-Austin	The University of Texas,, WRW 411A, Austin, TX 78712	Y
Brand Griffin	Boeing/HSV	499 Boeing Blvd., P.O. Box 240002 M/S JW-20, Huntsville, AL 35824	Y
Steve Price	Martin Marietta	P.O. Box 179, MS DC8082 Denver, CO 80201	Y
Patrick M. Galletta	Loral Aerospace	1760 Business Center Drive Reston, VA 22090	Y
James Verlander	Krug Life Sciences	1290 Hercules Drive #120-Space Station Service Office	Y
Behzad Raofi	CSR-UT-Austin	402 WRW, Univ. of Texas, Austin, TX 78712-1085	Y
Beau Chimene	MDSSC-Houston	MDCB2KE	Y
Maufred Leipold	UT-Austin	Aerospace Engineering Department, WRW, Austin, Texas 78712-1085	Y
Pierre Henri Pradel	UT-Austin	Aerospace Engineering Dept., WRW Austin, TX 78712-1085	Y
Ken Spratlin	CSDL MS2B	555 Technology Sq., Cambridge, MA, 02139	Y
Jose Lozano	UT-Austin	Aerospace Engineering Dept., WRW Austin, TX 78712-1085	Y
Jonette Stecklein	JSC	ET2	Y
Todd Wiersema	JSC	Lockheed-ESC, 2400 NASA Rd. 1, C50	Y
Mike Fraietta	McDonnell Douglas	1300 Bay Area Blvd., Houston, TX MDCA2	Y
Chad Goodman	Rockwell Intl.	2600 Westminster Blvd., Seal Beach, CA 90740, SX-10	Y
Alan Delamere	BALL	P.O. Box 1062, Boulder, CO 80304	Y
Colin Francis	Space Systems/ Loral	3825 Fabian Way, Palo Alio, CA 94303	Y
Lou Seiler	Harris/GASD	P.O. Box 94000, Melbourne, FL 32902	Y
Mel McIlwain	Aerojet	P.O. Box 13222, Dept. 5154, Bldg. 2019 Sacramento, CA 95813-6000	Y
Jerry Condon	JSC	ET4	Y
Tom Ramberg	Space Applications Corp.	4001 North Fairfax Dr., Suite 250 Arlington, VA 22203	Y
Ken Baker	NASA/JSC	ER2	Y
Elaine Stephens	NASA/JSC	EE7	Y
Malcolm A. LeComple	Aerodyne Research	45 Manning Rd., Billerica, MA 01821	Y

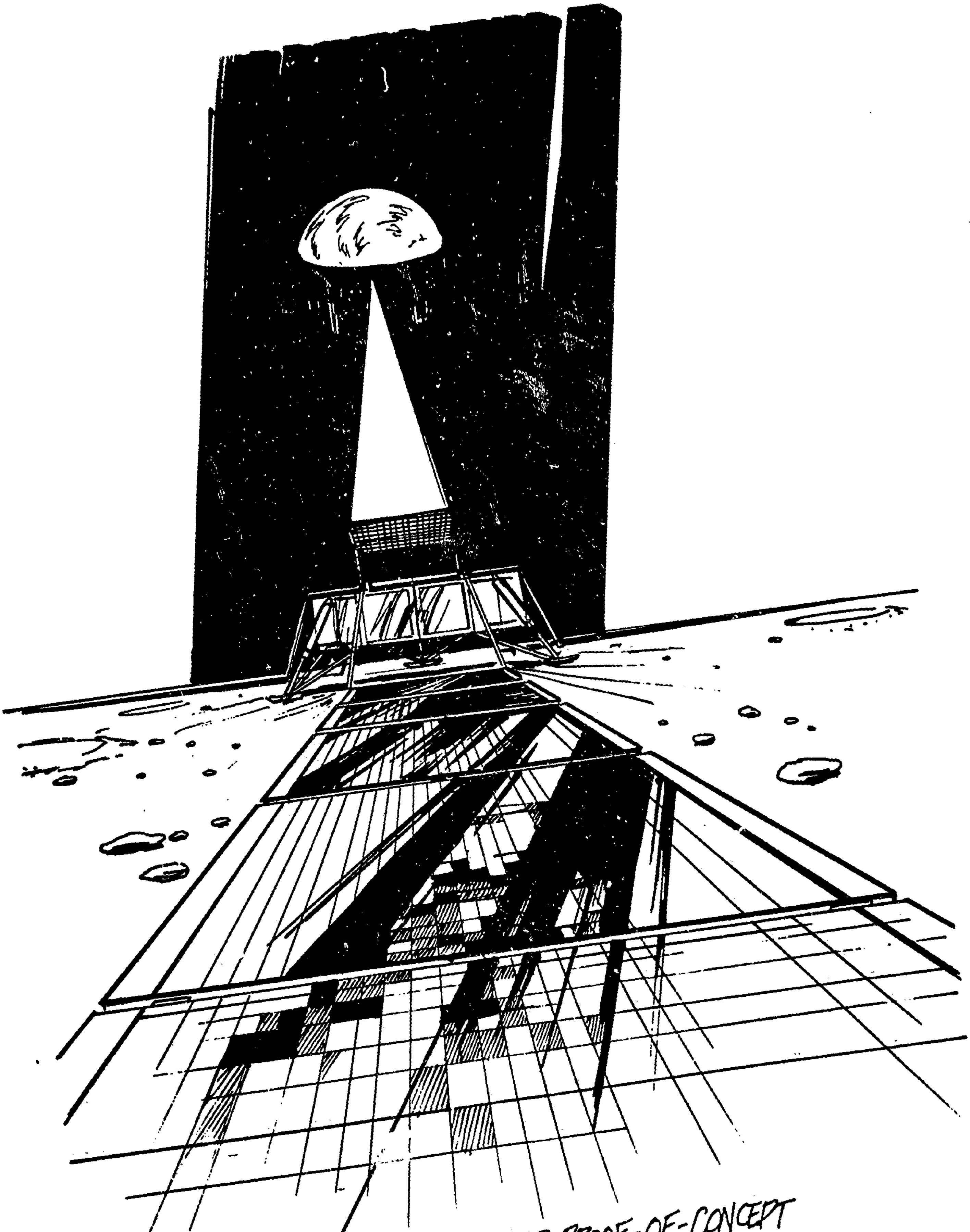
PAT RAWLINGS CONCEPT DRAWINGS



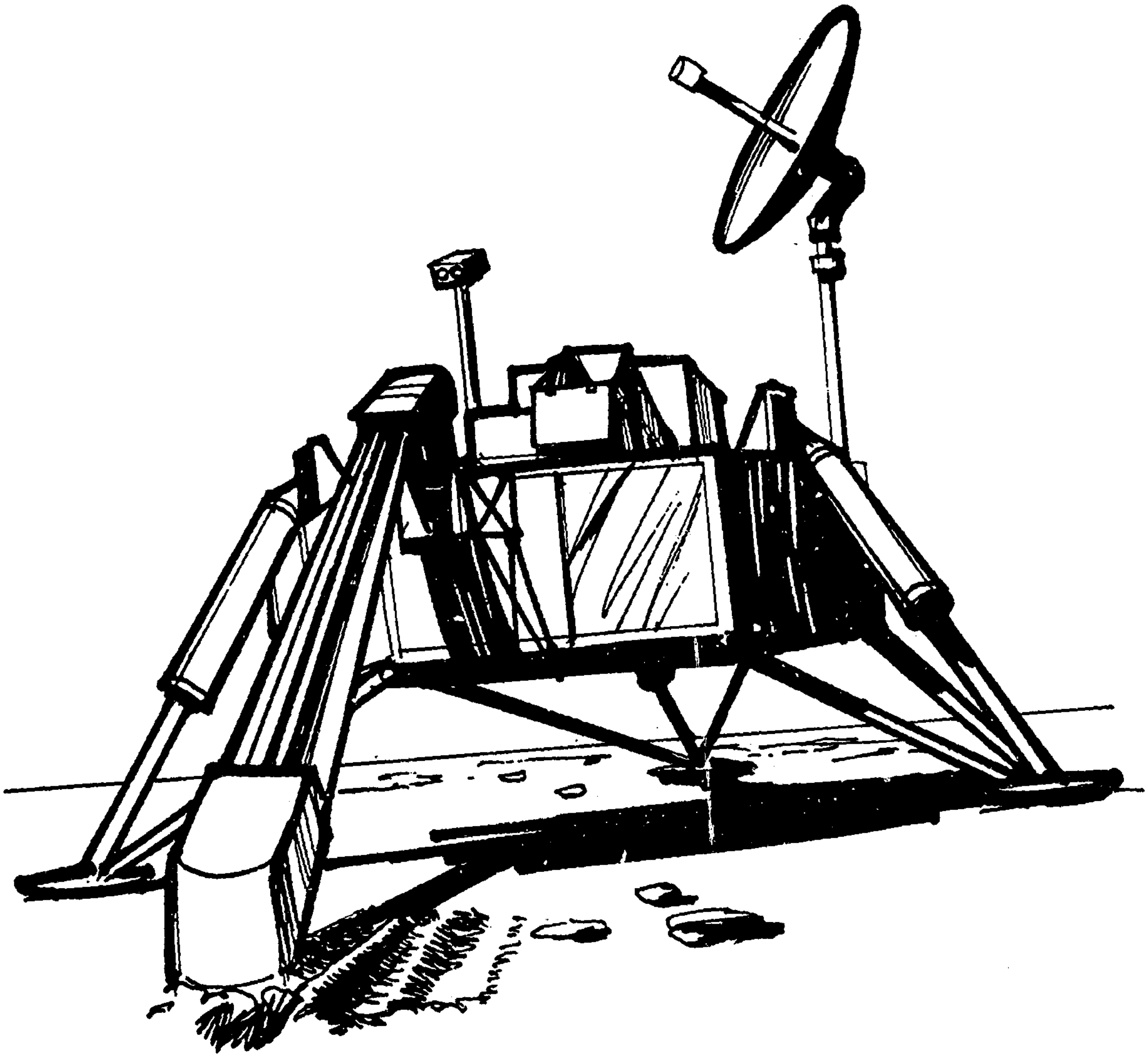




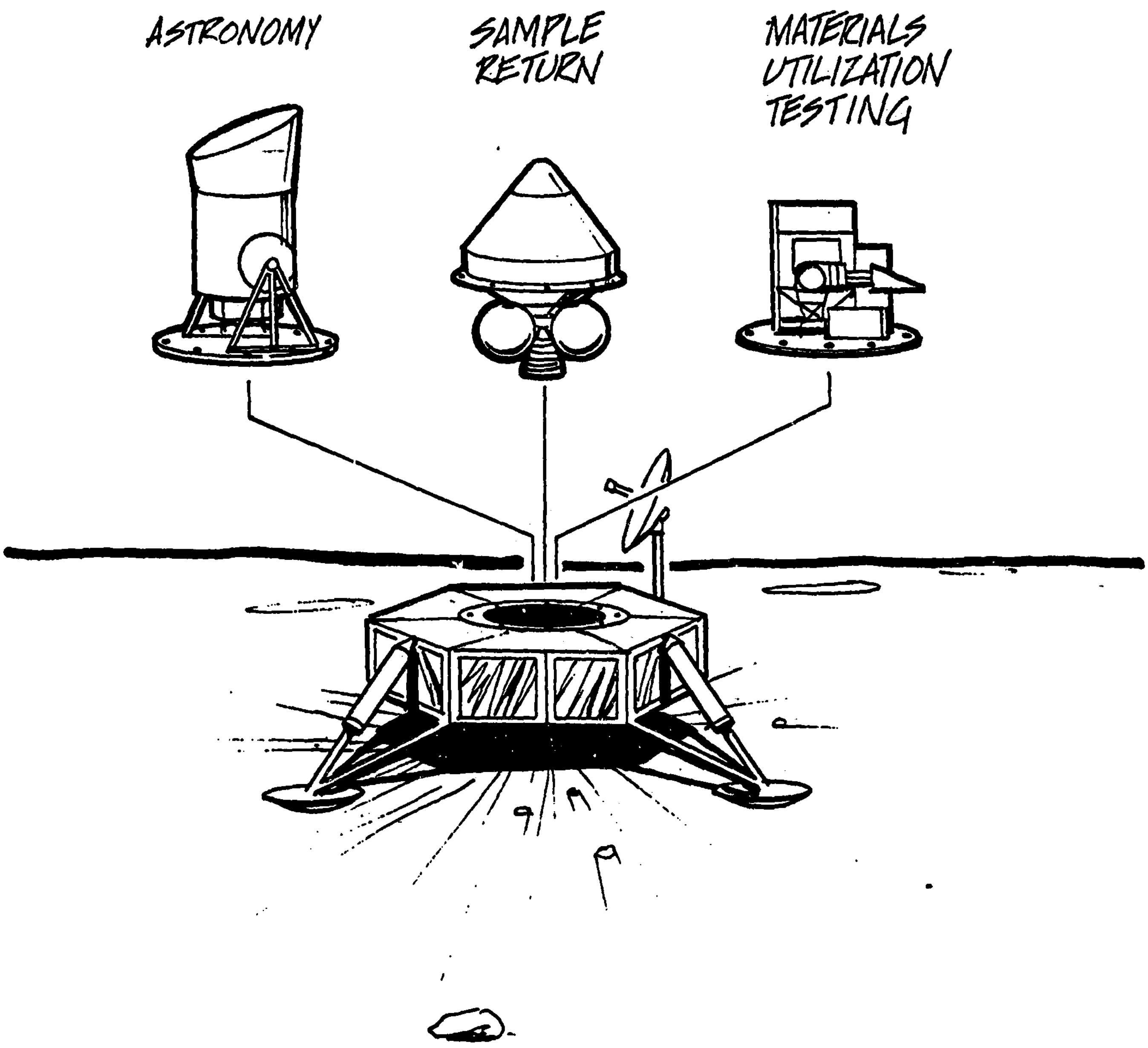
TETHERED MICRO-ROVERS



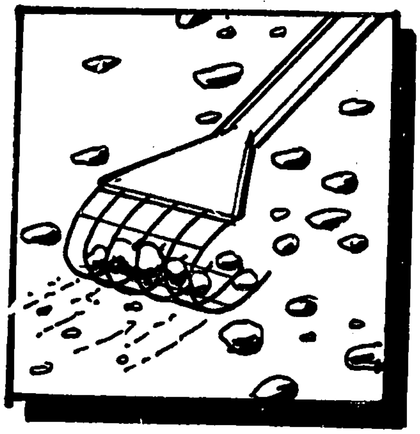
BEAMED POWER PROOF-OF-CONCEPT



ISMU PILOT PLANT
ON UNMANNED
LUNAR LANDER

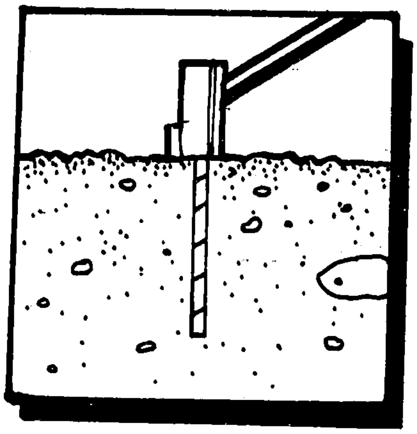


"BOLT PATTERN" PAYLOAD FLEXIBILITY



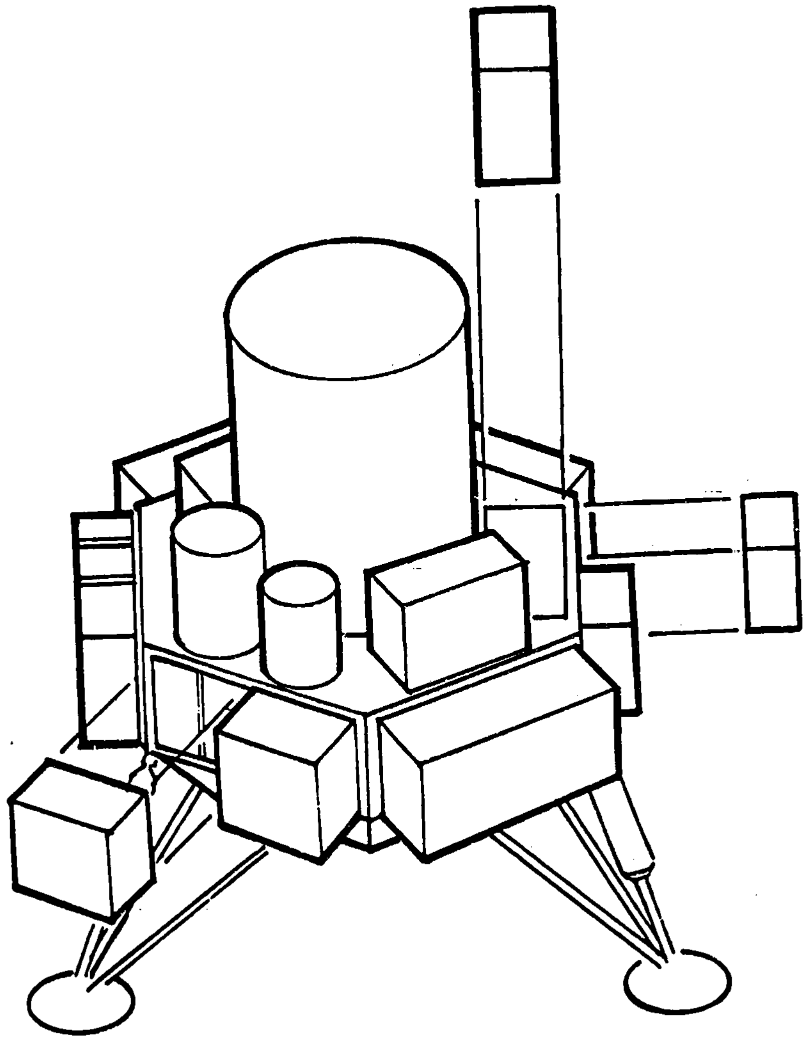
ROCK SAMPLES

SOIL SAMPLES

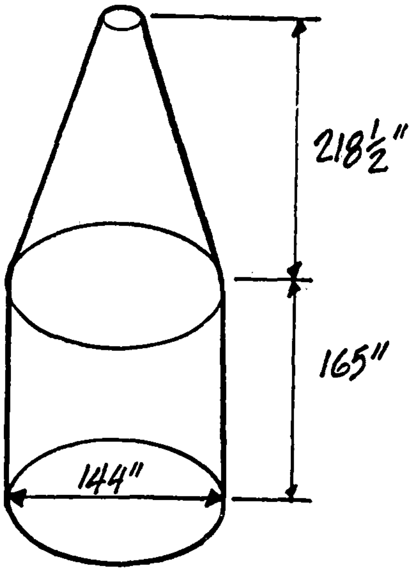


CORE DRILLING

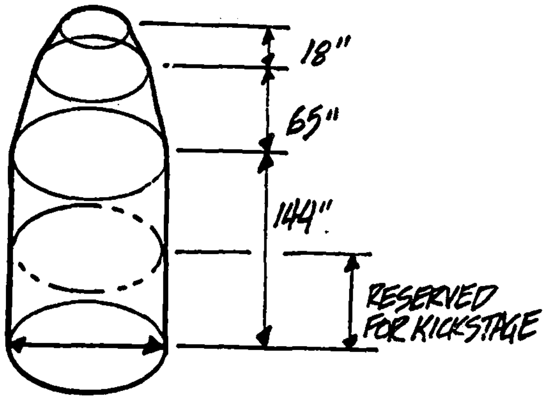
SAMPLE RETURN MISSION



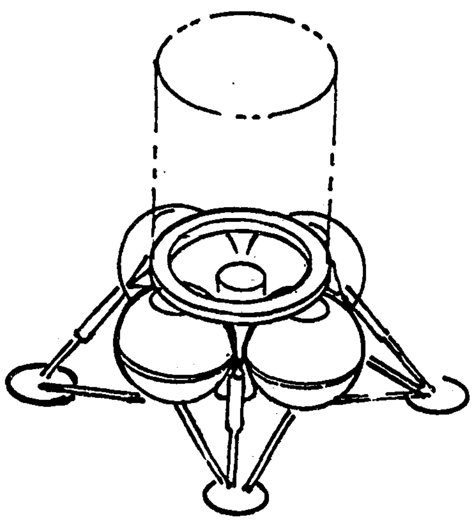
MULTIPLE
PAYLOAD OPTIONS



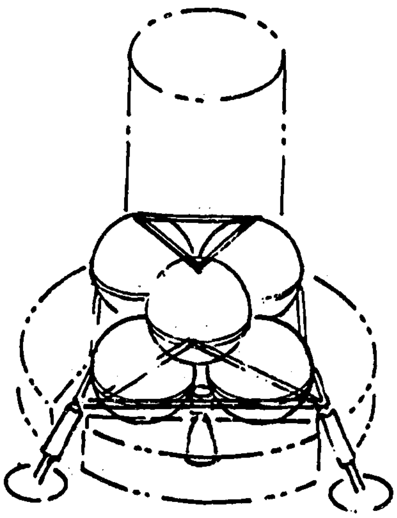
ATLAS
14 FT SHROUD



DELTA II



SYMMETRICAL
TANKAGE W/TOP MOUNT (4)
PAYLOAD - 1 INBOARD
ENGINE



CENTRALIZED TANKS (6)
MULTIPLE PAYLOAD LOCATIONS
3 INBOARD ENGINES

LIVE FROM THE MOON
REMOTE TV FROM LUNAR ROVER (MICRO-ROVER?)

LUNAR GEOSCIENCE

Exploration Science Strategy and the Common Lunar Lander

Paul D. Spudis

Lunar and Planetary Institute

Presented to the Workshop on the Common Lunar Lander

NASA-JSC

Houston, Texas

July 1, 1991

Geoscience Strategy
Elements

Global Reconnaissance

- Polar-orbiting remote-sensing
- Geophysical network
- Lunar atmosphere and environment

Site Reconnaissance

- Surface rover: traverses and *in situ* analyses
- Sample return missions (probes, rovers, humans)

Site Field Science

- telepresence robots
- humans

Lander Payloads

Lunar Surface Science

Return stage: Global access

- samples: rocks (bulk regolith, rake), soil (bulk, core)

UNRESOLVED: REQ. SAMPLE MASS, TYPES

Surface emplacement

- Geophysical stations and atmospheric experiments
  - lander emplaced
  - penetrator bus (release during descent)
- Rovers and walkers
  - *In situ* analyses and sample return
  - microrovers (multiple units deployed)

UNRESOLVED: STATION EMPLACEMENT, ROVER SAMPLE RETURNS, COMMON LANDER INSTRUMENTS (e.g., SEISMIC AND XRF AS LANDER CORE PAYLOAD)

Lunar Surface Science

Status of Science Issues for CLL

Exploration Science Strategy

- outlined, but details need to be refined
- no position on micro-rovers, others (?)

Sample returns

- global access, kg- mass requirments identified
- types of sample and acquisition methods in work

Environmental/Geophysical stations

- global access, measurement needs identified
- emplacement techniques in work

Surface rovers/ surface *in situ* measurements

- science and data requirements poorly defined

Lon Hood
Lunar & Planetary Lab
Univ. of Arizona
Tucson, AZ 85721

LUNAR GEOPHYSICAL MEASUREMENTS

Purpose:

To obtain an improved understanding of the internal structure and physical state of the Moon and its environment

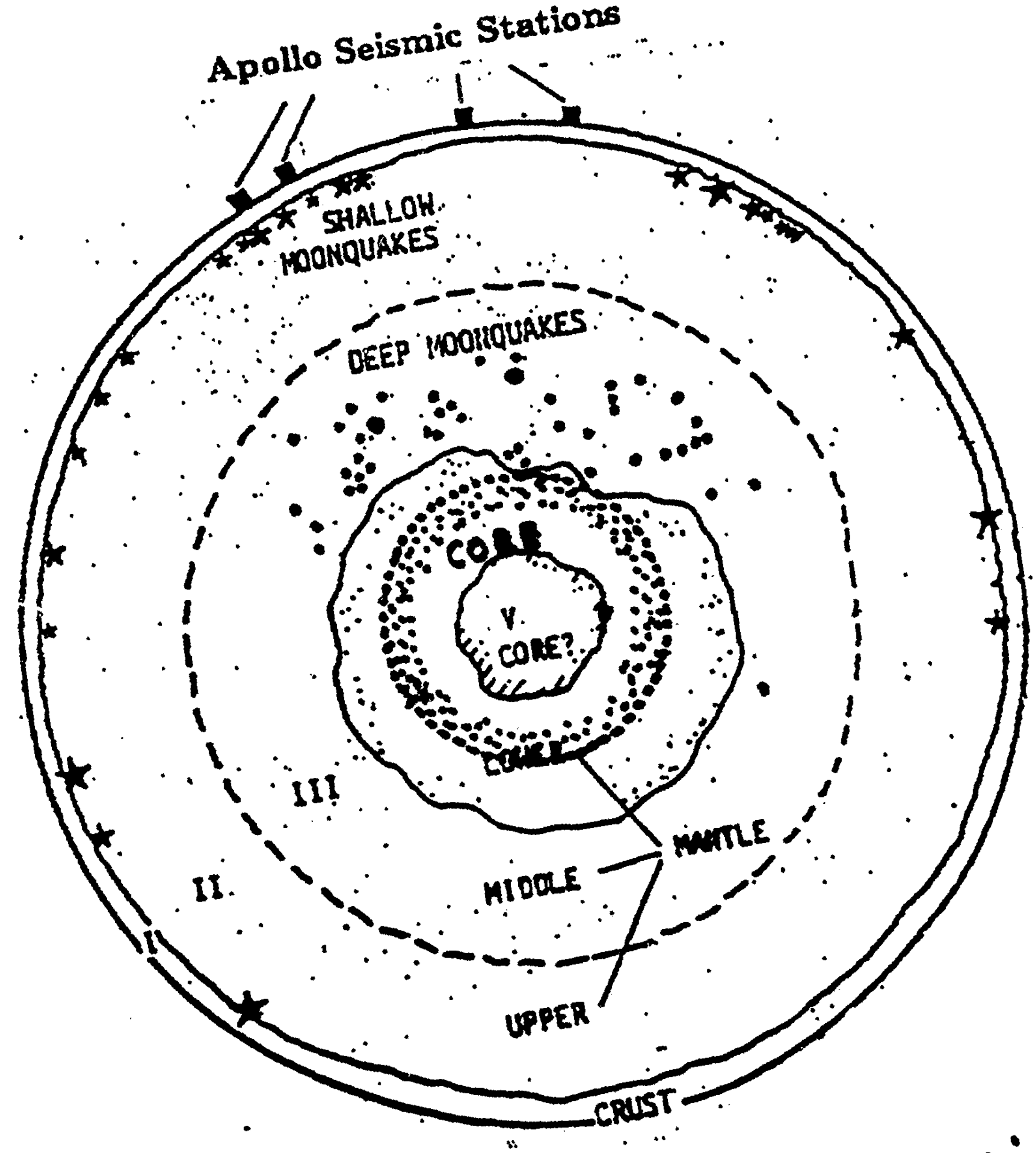
Typical Instruments:

(i) Seismometer
(ii) Heat Flow Experiment
(iii) Magnetometer
(iv) Mass Spectrometer
(v) Solar Wind Spectrometer

Major Questions:

Composition & Origin

(i) Existence and Mass of a Metallic Core
(ii) Composition and Structure of the Mantle
(iii) Composition and Structure of the Crust
(iv) Mean Lunar Heat Flow
(v) Present Temperature Profile
(vi) Origin and nature of the tenuous atmosphere
(vii) Origin of the paleomagnetism

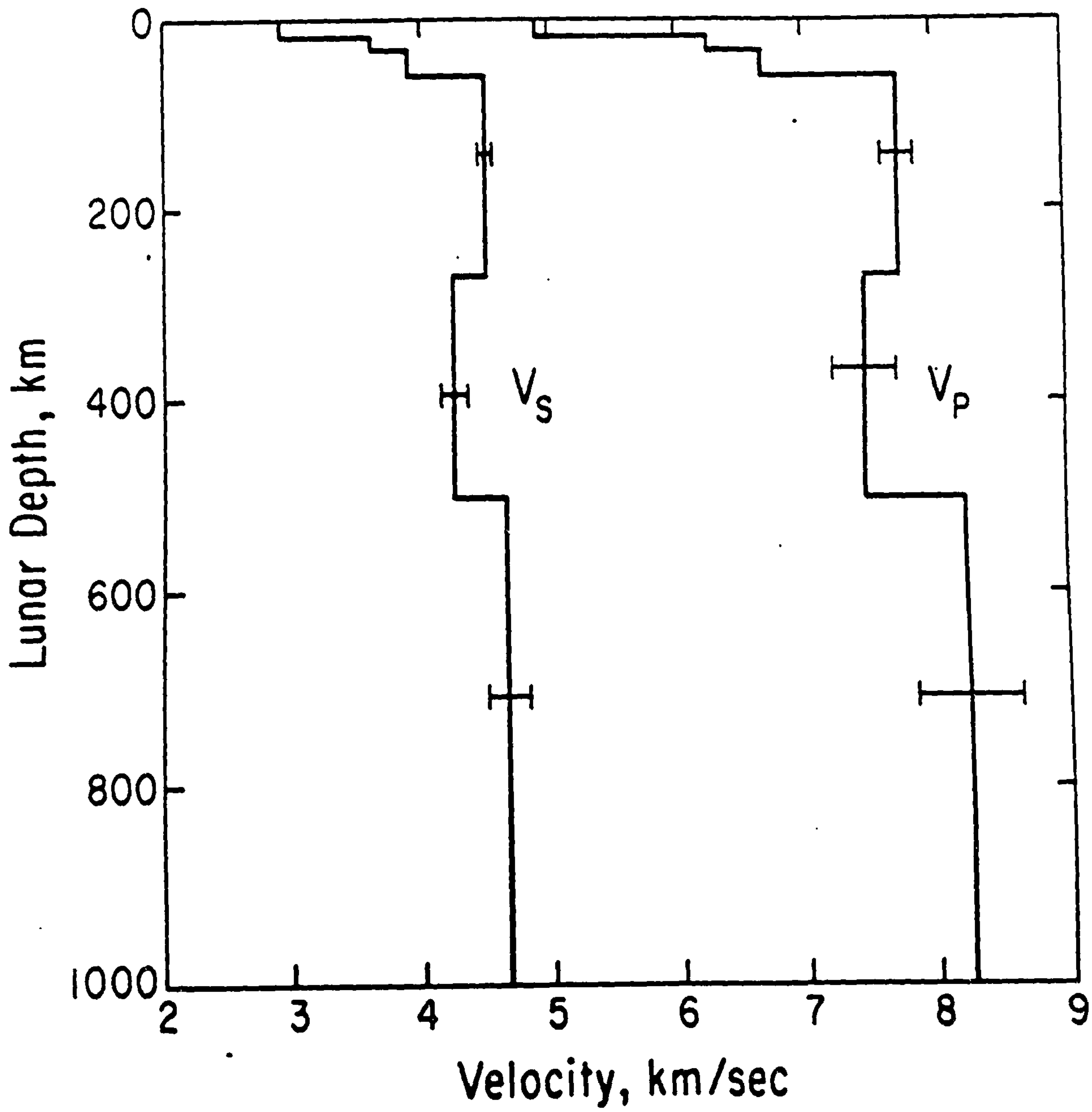


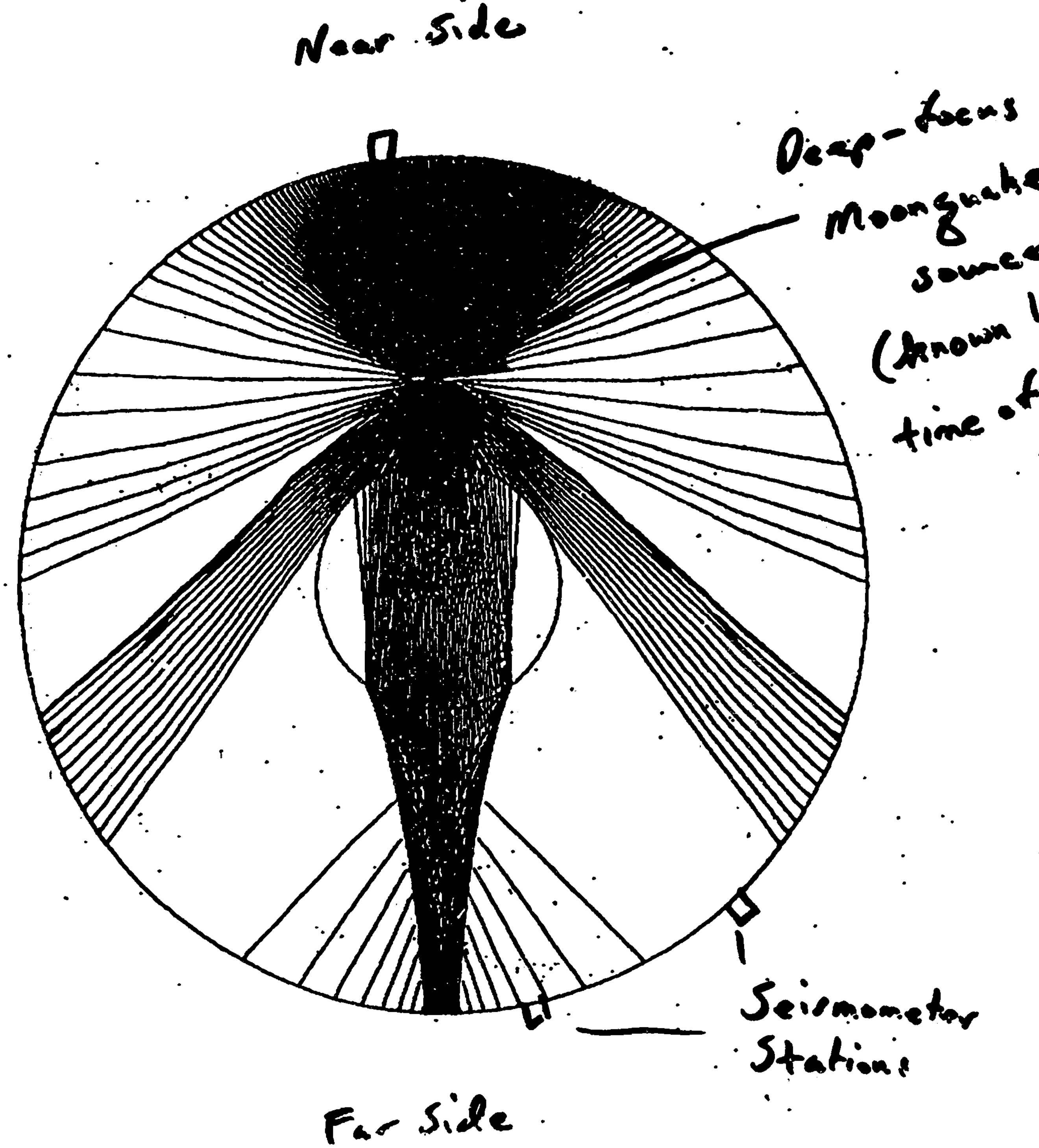
Main Deficiency: Small number & areal distribution of stations.

" for heat flow

ORIGINAL PAGE IS
OF POOR QUALITY

Y. Nakamura, 1983:

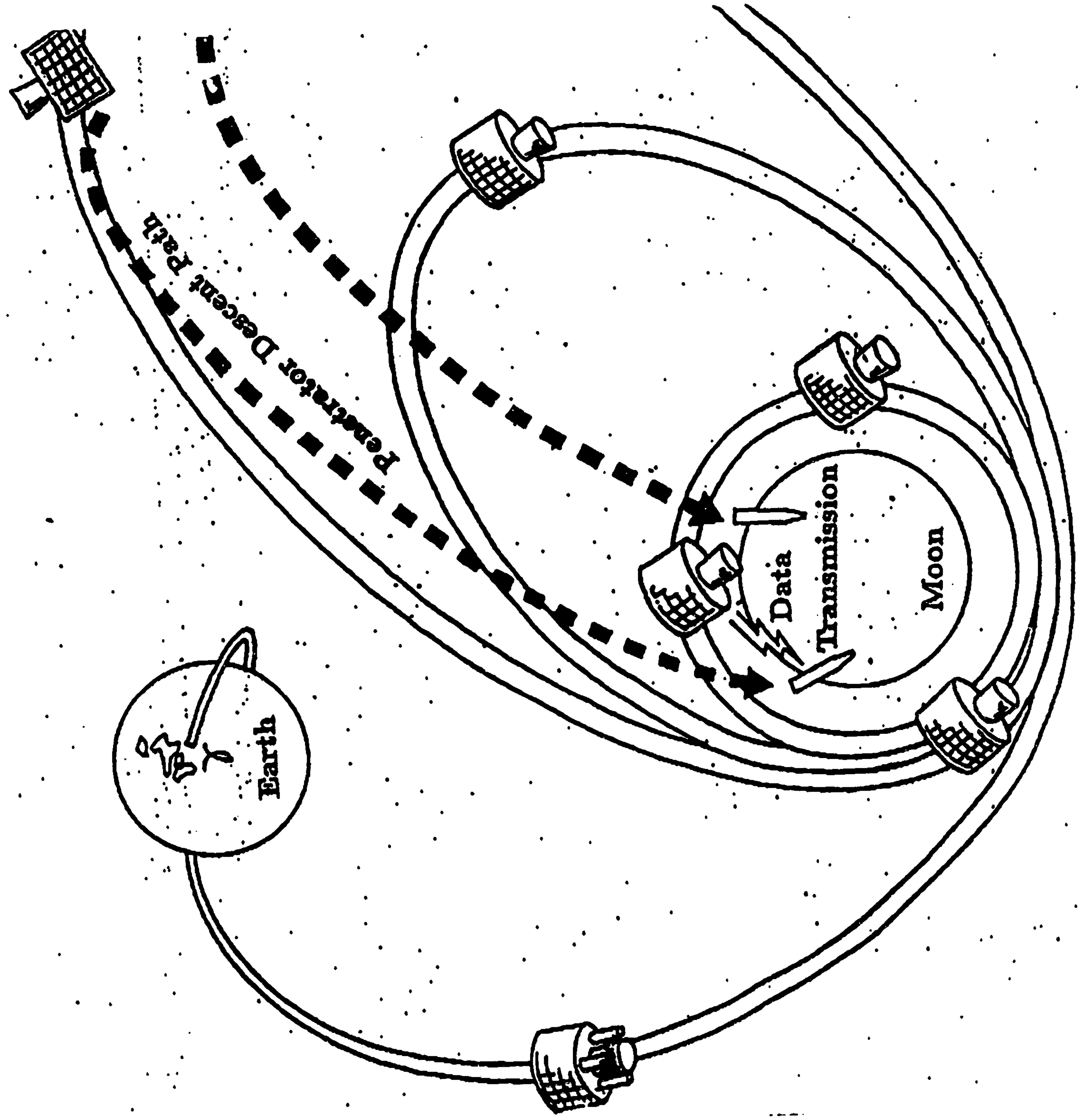




Near Side
Deep-focus
Moonquake
Source
(known location,
time of occurrence)
Seismometer
Stations
Far Side

METHODS OF DEPLOYMENT

- **Human**
- **Soft Landers / Rovers**
- **Penetrators**


Penetrator Descent Path
Data Transmission
Moon
Earth

ISAS PENETRATOR INSTRUMENTS

3-axis Seismometer:

Short-period, electromagnetic with resonant period ~ 1 sec. ~ 10 times more sensitive than Apollo seismometers at 1 Hz. Low power consumption (minimum threshold for recording; maximum recording length of ~ 10 minutes per event).

Heat Flow Probe:

10 temperature sensors along wall of penetrator; 2 thermal conductivity instruments; requires detailed analysis since penetrator disturbs thermal conditions in surrounding regolith; estimated error ~ 10%.

- Penetrators automatically emplace instruments at depths of 1-3 m in regolith.
  No drilling required!
- One orbiter can deploy multiple penetrators.

ISAS PENETRATOR CHARACTERISTICS

- Cylindrical shape with frustum nose, 82.6 cm long, 12 cm in diameter
- 2 spherical solid propellant motors; one is for de-orbiting and the other is for decelerating to < 300 m/s just before impact.
- 2 booms for balancing to allow spin stabilization
- Mass, excluding motors and booms, is about 13 kg
- Power provided by Lithium batteries.
- Instrument lifetime limited to ~ 1 year

Possible Approaches

1. "Smart" Soft Lander to deploy

   Seismometer } Drilling capability
   Heat Flow Probe } Drilling capability
   Magnetometer
   Mass Spectrometers
   Solar Wind Spectrometer

2. Combined Lander and Penetrator(s)

   Magnetometer } Lander
   Mass Spectrometers } Lander
   S.W. Spectrometer } Lander

   Seismometer } Penetrator(s)
   Heat Flow Probe } Penetrator(s)

CONCLUSIONS

1. Lunar geophysical instruments (seismometers, heat flow probes, magnetometers, etc.) should be deployed on the lunar surface with capabilities similar to or better than those of Apollo but with a much wider distribution.

2. Some instruments (e.g., mass spectrometers, solar wind spectrometers) can be deployed by relatively simple soft landers.

3. Other instruments (e.g., seismometers and heat flow probes) require drilling capability and location away from other instruments; deployment of these instruments would require a more complex and expensive lander.

4. Penetrators provide an alternate, less expensive, option for deploying seismometers and heat flow probes. Advantages include: (a) instruments are automatically emplaced a few meters beneath the surface so that drilling/roving capability is not needed; (b) more than one geophysical station can be deployed in a single lunar mission; (c) careful design to minimize power consumption may allow use of lithium batteries rather than RTG's for each penetrator. Disadvantages include: (a) lunar penetrators require retro motors for deceleration prior to impact; (b) since some stations will be on the far side, communication will require an overhead orbiter; (c) penetrators must be released

from lunar orbit over a period of about 1 month to allow a wide distribution.

5. It may be possible to combine a lander and penetrator mission to allow several geophysical stations to be established at widely separated locations in a single mission. A much simpler (and less expensive) lander could be used.

John Freeman

Instruments list for the Lunar Geophysics Network, Seismic and Heat Flow

Additional Detectors	Weight	Power
1. Neutral Gas Mass Spect.	10 kg.	7.5 Watt
2. Dust Detector	10	8
3. Ion Mass Spect.	5	5
4. Electron Energy Spect.	5	5
5. Magnetrometer	5	5
6. Electric-Field Meter	20	10
7. Solar Wind Detector	5	5

I would like to suggest that at least one station be located near a suspected lunar transient site to look for possible episodic or transient events

W. David Carrier, III
Director
P.O. Box 5056, Lakeland, Florida 33807-5057

I think that there are a number of important geotechnical issues that could be addressed with the lunar lander. Please add the following to your shopping list of potential payloads:

1. Detailed topographical maps of landing sites: say 10-cm contours over an area 1 km in radius
2. Detailed boulder sizes and counts over the same area
3. Buried boulder surveys: ground-penetrating radar? microwave?
4. Survey of depth-to-bedrock: how defined?
5. Trenching and bulldozing experiments; depth limitations (could also be combined with geological investigations of the regolith)
6. Drilling and coring: energy consumption; depth limitations (could be part of your already-proposed sample return mission
7. Detailed cone penetrometer measurements: force vs. depth (very useful for siting of lunar base habitats and equipment, especially a settlement-sensitive structure such as a telescope)
8. Trafficability measurments: distribution of energy consumption; slope-climbing; rutting; performance on surfaces not previously explored, such as pyrochastic deposits and lava sheets (applies to other items as well)
9. Electrostatic charge measurements

IN-SPACE MATERIALS UTILIZATION

NASA

Soft Lander Experiments

ISMU Session Agenda

1:00 Introduction - Tom Sullivan / JSC

General Concepts - Dave McKay / JSC

ISMU Eng'g Test Bed / Terry Triffet / Univ. of Arizona SERC

Volatiles Experiments - Jim Jordan / Lamar University

Automation and Control - Web Marner / JPL

Others as time permits

3:15 Summary Period

3:45 Break

4:00 Rejoin as one meeting

T. A. Sullivan 7/1/91

NASA

Lunar/Mars Resource Exploration and Utilization

- Goals and Objectives
  - Develop an architecture-independent strategy for resource utilization
  - Develop a supporting science exploration program
  - Develop and demonstrate resource utilization technologies
  - Use new data from this program to shape and focus architectures at a series of decision points

There are no requirements for an ISMU Robotic Program in the absence of a strategy to employ lunar resources.

SOLAR SYSTEM EXPLORATION DIVISION

NASA

Soft Lander Experiments

Synergy with:

- Surface Science - Sample return missions, chemical analysis
- Astronomy -
- Science payloads - atmospheric science, geology
- Engineering and Technology - rovers, teleoperation,
- Life Sciences - radiation protection
- Outpost needs - dust control, oxygen, fuels, early capabilities

T. A. Sullivan 7/1/91

NASA

Soft Lander Experiments

Near term

- Prospecting? resource mapping? sample return?
- Systems studies of chemical eng'g designs in lunar environment
  - Solids flow in hoppers
  - Size separation of soil via screens, air classifiers
  - Fluid bed behavior
  - Pneumatic conveying behavior
  - Long term lifetime of valves, bearings, wheels...
  - Effect of temperature cycles, vacuum, and radiation on materials

T. A. Sullivan 7/1/91

NASA

Soft Lander Experiments

Near term (cont.)

- Physical processing of regolith (combined in one unit?)
  - Cast basalt
  - Sintered blocks
  - Volatiles *release* (thermal, mechanical, microwave)

- Physical interaction with regolith
  - Mining precursor studies
  - Trafficability precursors

- Measure of radiation protection
  - Soil
  - Densified regolith

T. A. Sullivan 7/1/91

NASA

Soft Lander Experiments

Mid-term

Rovers for regional analysis and "rendezvous and dumping" tests

Mining vehicle tests

Pneumatic mining tests

Chemical processing tests using leading oxygen routes (subsystems) product and process dependent

Volatiles *processing* experiments for H2, H2O, CH4, and He-3

Production and stock-piling of cast or sintered blocks for radiation protection, landing pad, dust-off porch, roads, thermal energy storage

T. A. Sullivan 7/1/91

NASA

Soft Lander Experiments

<u>Strawman Requirements</u>

- 1st launch in mid 1995
- Payload capacity ~200 Kg
- CLL Lifetime - 5 day transit, 14 days in orbit, 1 lunar daylight period
- Global lunar access to lighted surface areas
- 2 km circular landing accuracy
- Access to surface for sampling, unloading
- Access to hemispherical view of sky
- Communications - 200 kbps down, 20 kbps up
- Power - 100 kW during trans lunar coast

T. A. Sullivan 7/1/91

NASA

Soft Lander Experiments

<u>Summary, Conclusions, and Recommendations</u>

- Are the strawman guidelines adequate?
- How many experiments can we justify?
- Do we <u>need</u> any landers at all?
- Do we tie an ISMU program to the common lunar lander program?
- What payload/experiment concepts can we recommend?
- What areas of research are most needed? (timing and potential)

T. A. Sullivan 7/1/91

AN ISMU/ENGINEERING TEST-BED

for Precursor Missions to the Moon and Mars

OBJECTIVE: To identify the technologies, perform the system experiments, build an operating model, and write the specifications for a compact flight-qualified oxygen processing module that will both demonstrate the viability of Indigeneous Space Materials Utilization (ISMU), and test the extended operation of the system and its components under realistic conditions.

BACKGROUND: Though it may be possible to establish Outposts on the Moon and Mars by transporting everything required from Earth for short stays and a limited set of scientific experiments, few experts doubt that local resources must be utilized for extended habitation and full-scale development.

Propellants, oxygen and hydrogen in particular, are perhaps the most important products that must be produced locally, in order to save their transportation costs, but almost equally important will be the need to produce metals, ceramics and composites for construction and other products, such as heat and radiation shields, glass sheets, thin flexible films, pipes, solar collectors and photovoltaic cells.

The implication is that an ISMU system should be developed and tested, so that it could actually produce small quantities of oxygen, refractories and other materials during the Outpost phase.

But because of the difficulty of accurately simulating environmental conditions, chemical, mechanical and electrical systems created and tested on earth, even when cast in flight-qualified hardware, may not function properly on the surface of the Moon or Mars. For example, fluids may not behave as required to sustain reactions in microgravity, linkages may lock from lubricant loss, filters may clog with dust, pumps may freeze or fail to produce required flow rates, electronic components may suffer unpredictable radiation damage, and so on.

For this reason, these potential failure modes should be explored on one of the Small Landed Precursor Missions to assure the successful operation of such systems during the Outpost phase. And because of the variety of representative subsystems and components it must contain, as well as the pressing need to study its operation under realistic conditions before production is attempted, it is proposed that an ISMU module of the type described be selected for the test system.

Common Lunar Lander Payload Data Sheet

Payload Name:

Purpose of Payload:

Desired Landing Site(s) (Feature Names, Lat., Long.):

Mass (kg)

Dimensions (length, width, height, volume; meters)

Experiment Duration:

Power Profile (Max., coast, setup, day, night; watts)

Telemetry: Uplink bps: Downlink bps:

Setup Requirements: Remain on lander? Drilled into regolith?

Set on surface? What distance from lander?

Additional Requirements:

APPROACH: An ISMU module of this kind, applicable for both lunar and martian conditions, is being developed at the University of Arizona Space Engineering Research Center. With the minimal additional support detailed in the accompanying budget, the system could be ready for construction by a qualified aerospace contractor within eighteen months from the starting date.

The current state of the processing system selected for the development represents the second stage of a three-stage process featured in the UA/NASA SERC approach to ISMU. Promising candidate processes are first screened for technical feasibility in the light of rapidly emerging new technologies, scientific merit, cost-benefit to space missions, and overall Figure-of-Merit. Those that survive are then subjected to test tube scale experiments, engineering issues are addressed and complete system integration demonstrated.

Finally, the most promising candidate is selected for a bench scale demonstration, which ordinarily involves an increase in processing rates of at least one or two orders of magnitude. If, for example, as in the present case, 10 grams of oxygen/day are produced at test tube scale, 1 kilogram of oxygen/day will be produced at bench scale. Concurrently, uses of process byproducts are integrated, the system is automated, and a computer model is developed.

A schematic diagram of the facility in which the present development is taking place is presented in Figure 1. Currently, the Small Scale Test Bed is operational, has produced the single ZrO_2 oxygen cell results described in the AIAA publication of Appendix A, and is running methane production and water electrolysis experiments at test tube scale. Additionally, the structure to house the Large Scale Test Bed for the bench scale demonstation is in place, the necessary utilities are contracted, the plans for the 16 cell oxygen production unit are complete, and the Sabatier and Water Electrolysis systems on loan from United Technology/Hamilton Standard and NASA/JSC are on the way. A preliminary computer model of the oxygen production system, an animation of which is shown in Figure 2, has been developed and qualitatively keyed into the engineering database.

An automated control and monitoring system featuring distributed intelligence, hierarchical structure, and integral communications is also under development and has been implemented for the Small Scale Test Bed (see Figure 1). This consists of smart sensors and a local controlling computer connected via an ethernet communication system to a remote commanding computer with appropriate telemetry display and control functions. The final design will employ distributed supervisory control by intelligent agents, advanced artificial intelligence, and human interaction in such a way as to maximize autonomy and fault tolerance, while conforming to space mission communication standards.

DEVELOPMENT PLAN: Within the scope of the present proposal the following will be accomplished:

1. The Large Scale Test Bed described above will be expanded to demonstrate byproduct use by producing a useful organic material, either bulk polyethelene or a simple lubricant, depending on the result of feasibility studies.

2. Plans and specifications for the final processing system module will be prepared to meet flight qualifications as outlined by experts at JSC, JPL, ARC, and appropriate aerospace industries.

3. Plans and specifications will be prepared for a communications link to be implemented between the emplaced module and UA/NASA SERC for purposes of continuing observation and experimentation during missions.

FUTURE PLANS: Development of the Large Scale Test Bed will continue, with the objective of incorporating regolith processing in the above system. Projects featuring several different methods of recovering bound oxygen and a variety of other useful substances from lunar and martian soils and rocks are underway at UA/NASA SERC. The optimum process has not yet been determined, but since several promising candidates involve CO_2 production at some stage, it is highly likely that a fully integrated system can be created.

When this has been accomplished, a proposal will be submitted to perform flight qualification experiments for the entire system, as for the subsystem featured in this proposal, and to prepare plans and specifications for a full-function ISMU module to be flown on later missions. This module will be capable of producing, not only larger amounts of oxygen and the products noted above, but also metal and refractory materials for construction, shielding, and other products; and again experiments will be conducted and the functions of the module monitored from UA/NASA SERC.

Based on the operational experience gained from these Small Landed Precursor Missions, plans and specifications may then be prepared for fully integrated, reliable ISMU plants to support NASA missions of increasing size, duration and complexity.

5/8/91

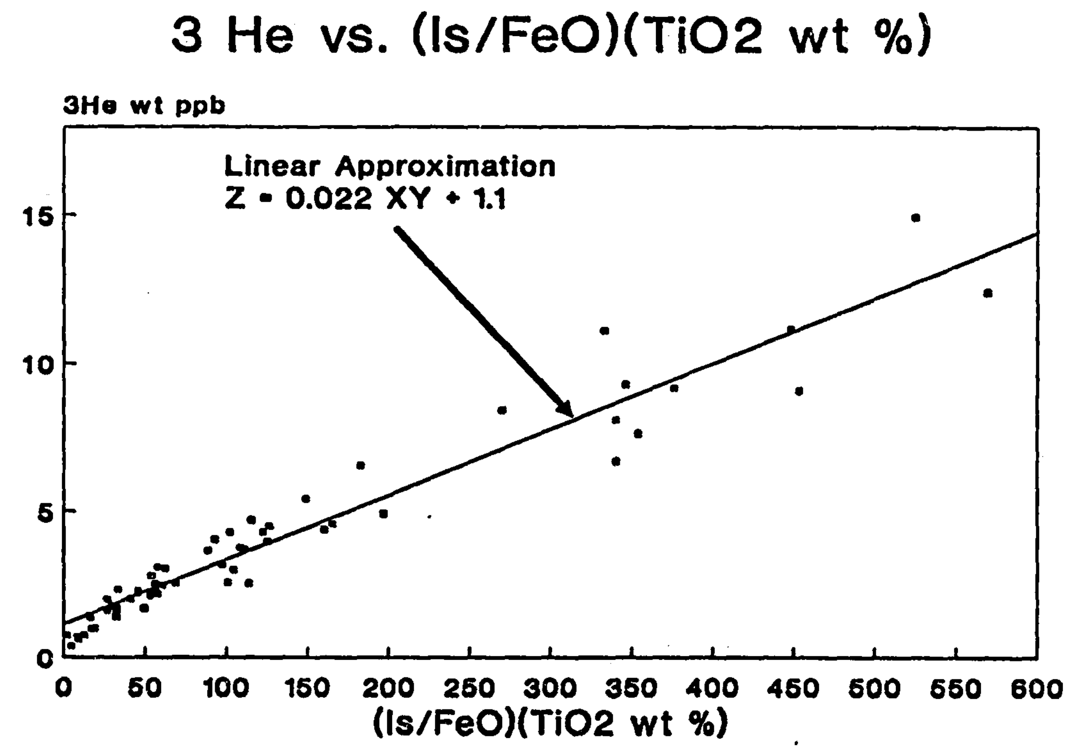


Fig. 1 3He vs. (Is/FeO)(TiO2 wt %)

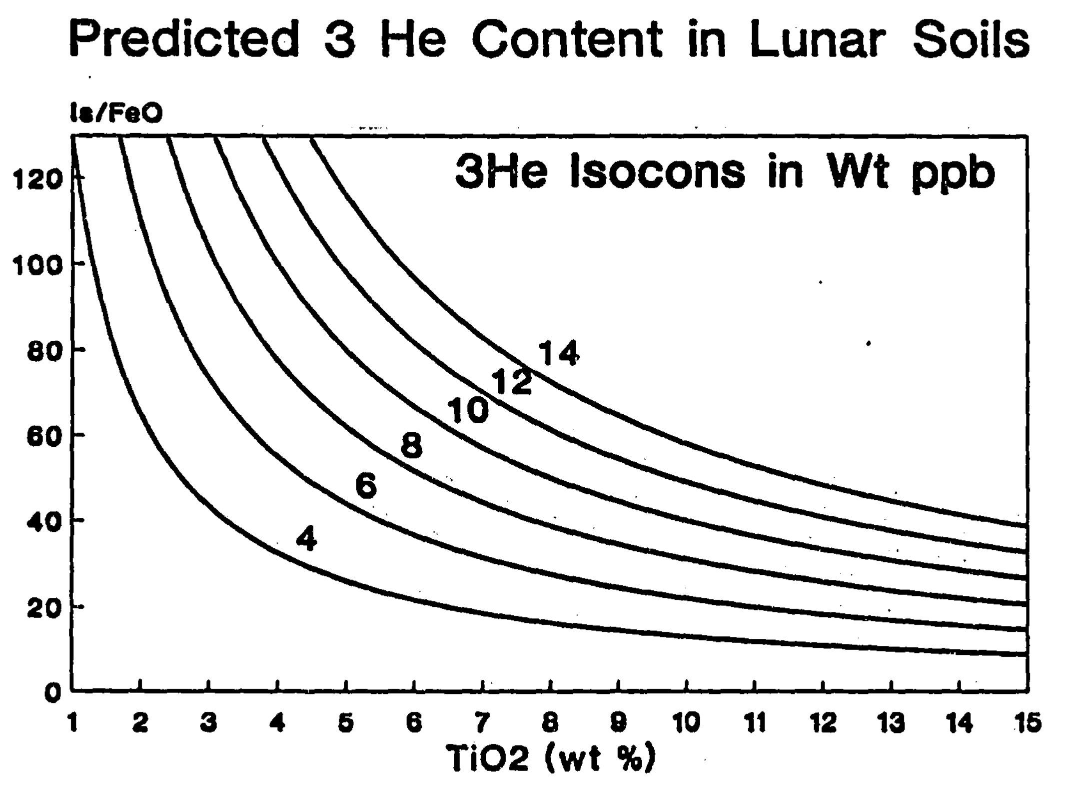
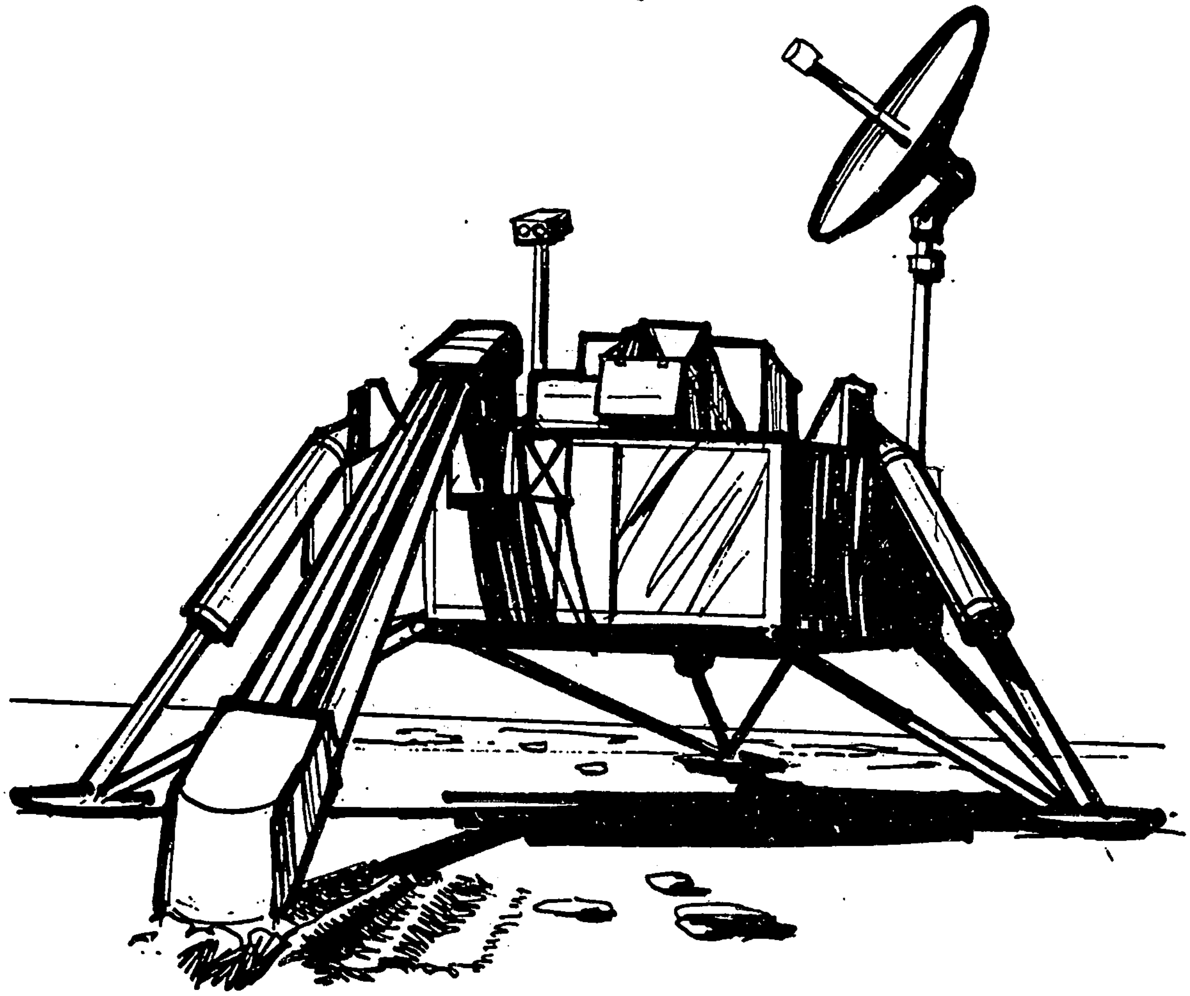


Fig. 2 Predicted 3He Concentration in Lunar Soils

NAG9-376

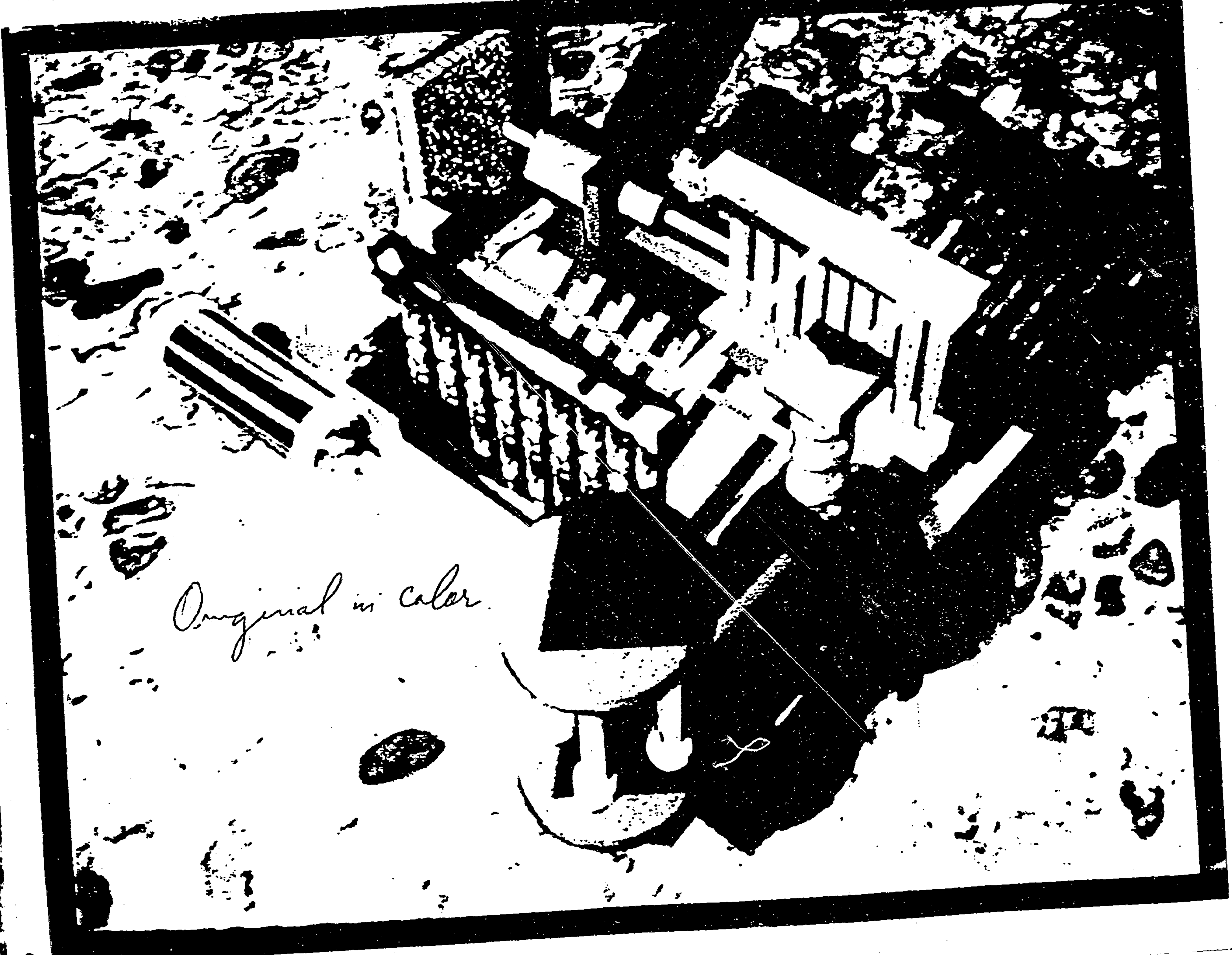


ISMU PILOT PLANT
ON UNMANNED
LUNAR LANDER

SAIC.
Science Applications International Corporation
An Employee-Owned Company

Title
Date 7-1-91
Scale NONE
Contract #
Name Pat Rawlings
Page of

17049 El Camino Real, Suite 202, Houston, TX 77058 (713) 244-3800 FAX (713) 244-3830


Original in color.

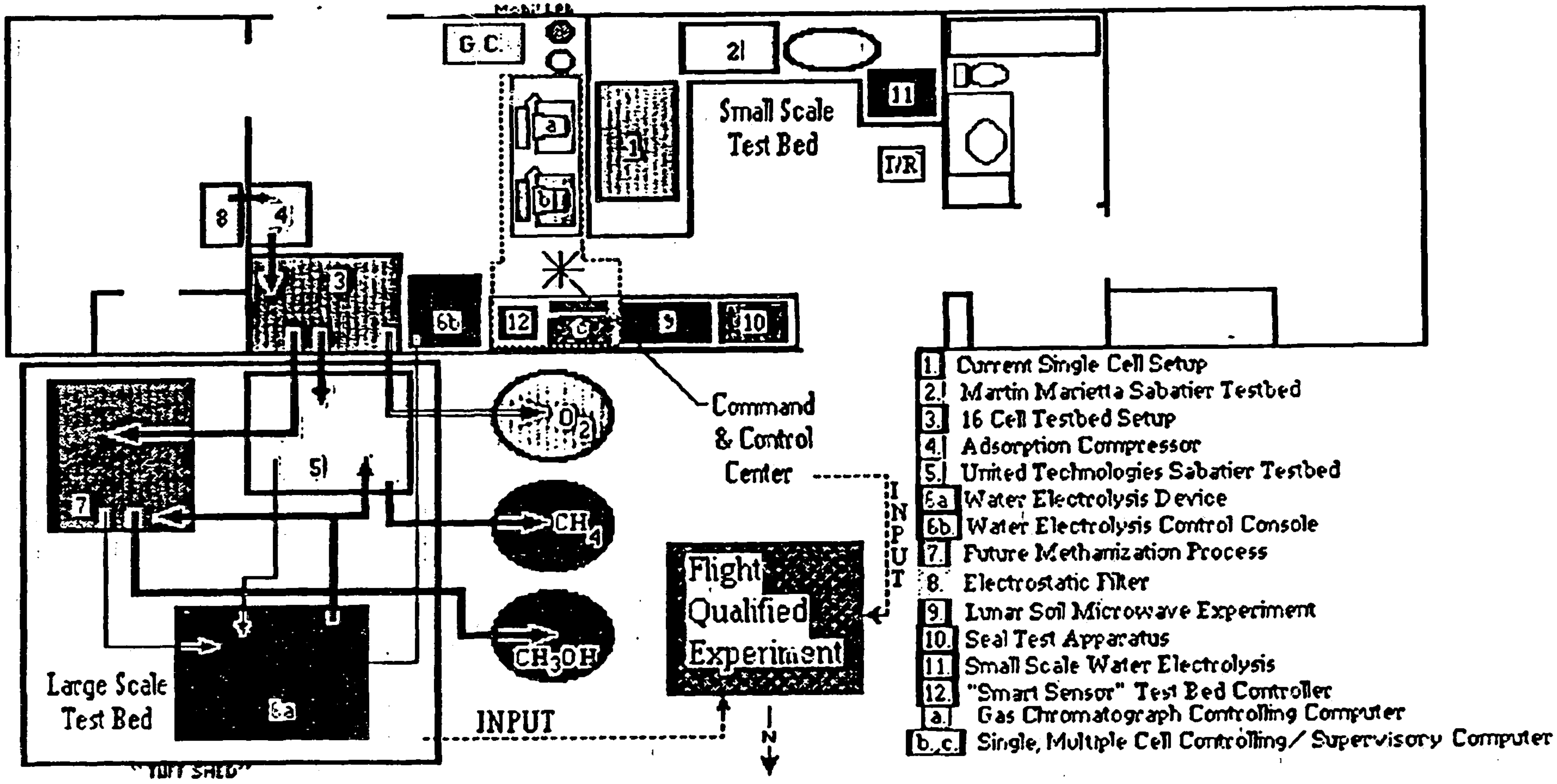


FIG. 1 UA/NASA SERC ISRU/ISMU LAYOUT

Fusion Technology Institute

Nuclear Engineering and Engineering Physics Department
University of Wisconsin–Madison

Memorandum to Stephen Bailey
Re: Verification of He-3 potential of Mare Tranquillitatis
From E. N. Cameron, Wisconsin Center for Space Automation and Robotics, University of Wisconsin, Madison, WI 53706

Helium-3 potential of Mare Tranquillitatis

During the past several years, our study of the He-3 resources of the Moon has focussed attention on the regolith of Mare Tranquillitatis, for the following reasons:

1. It is easily accessible.
2. The mare is very large, roughly 300,000 sq. km.
3. High-titanium regolith was sampled by Apollo 11 and found to contain 34 to 44 wppm total helium.
4. Remote sensing by gamma-ray spectroscopy and spectral ratio mapping indicates that large areas of the mare are covered by high-Ti regolith that should have helium contents in excess of 20 wppm He.

Detailed studies of geologic maps of the mare, plus plots of craters deep enough to have blocky ejecta halos on high-resolution photographs of the Ranger VIII and Apollo 11 areas, together with measurements of the areas occupied by such craters indicate that about 50 percent of the area of the mare should be physically minable with appropriately maneuverable mining machinery capable of handling and discarding small ejecta blocks.

Detailed studies of small young craters on high-resolution photographs indicate that the average depth of regolith in physically minable areas is about 4.5 m.

A map of Mare Tranquillitatis showing the distribution of three categories of regolith, on the basis of TiO_2 content, has been prepared (Fig. 1). The map is based on the UV/IR photo of E. A. Whitaker, calibrated against the spectral ratio map of Johnson et al. (1977).

Data from Apollo 15, 16, and 17 drill cores show variation in He content of regolith with depth but no systematic trend with depth. Decline in He content of regolith with depth, to the depths reached in the drill cores, is not indicated, and studies of very small craters suggest that no decline is to be expected.

On the basis of the above, an estimate of He-3 resources in minable regolith of Mare Tranquillitatis, as shown in the attached table, has been prepared. Note that for purposes of estimating tonnage of regolith, an average depth of minable regolith of only 3 m. has been used. For purposes of estimation, 50 percent of the area of Mare Tranquillitatis is taken to be physically minable, as concluded from crater studies.

The estimate is obviously a preliminary one, but the work which led to it has achieved its purpose, which was to determine whether or not Mare Tranquillitatis has the potential for being a major source of He-3 for producing energy by fusion with deuterium. Clearly it does, and the systematic exploration necessary to define minable areas in Mare Tranquillitatis, to determine the tonnages of minable regolith in them, and to calculate their helium content, is a logical step toward developimg the resources of the Moon.

Necesssary work:

1. Determination of variations in depth of regolith and distribution of blocky regolith in relation to craters of various sizes and ages. This can probably best be done by a rover equipped with ground radar, on traverses planned with the aid of high-resolution photographs. This information would permit delineation of physically minable areas.
2. Determination of variations in He content of regolith with depth, by core sampling at various points in areas of high, intermediate, and low He content as defined under 3. Holes should reach depths of at least 3 m., preferably 4 m.
3. Calibration of existing spectral reflectance maps of Mare Tranquillitatis regolith against He content as shown by sampling of various reflectance units and analysis for He. As pointed out by Paul Spudis, such calibration is needed to resolve discrepancies between, and uncertainties of, various reflectance surveys. Calibration would then permit delineation of mare areas of high (>30 wppm), intermediate (20-30 wppm), and low (<20 wppm) He. Representative areas of each category could then be sampled to check on variations in helium content of regolith with depth. The use of well calibrated reflectance maps as a control on sampling could drastically reduce the numbers of surface samples and drillhole samples required for accurate evaluation of the helium resources of Mare T. Preparatiom of the maps should therefore have a high priority in the exploration program.
4. Acquisition of bulk samples of regolith (10-20 kg) for testing procedures for gas recovery and separation on Earth, and also for testing procedures for oxygen production from regolith.

All the above steps could be accomplished within the framework of the CLL as I understand it from the workshop. The results would be of major significance, because they would provide the basis for a firm estimate of the tonnage and He-3 content of minable regolith in Tranquillitatis. This is the necessary prelude to determining the economic viability of helium mining on the Moon and to planning mining operations.

Eugene N Cameron

E. N. Cameron
July 8, 1991

Copy to Paul D. Spudis

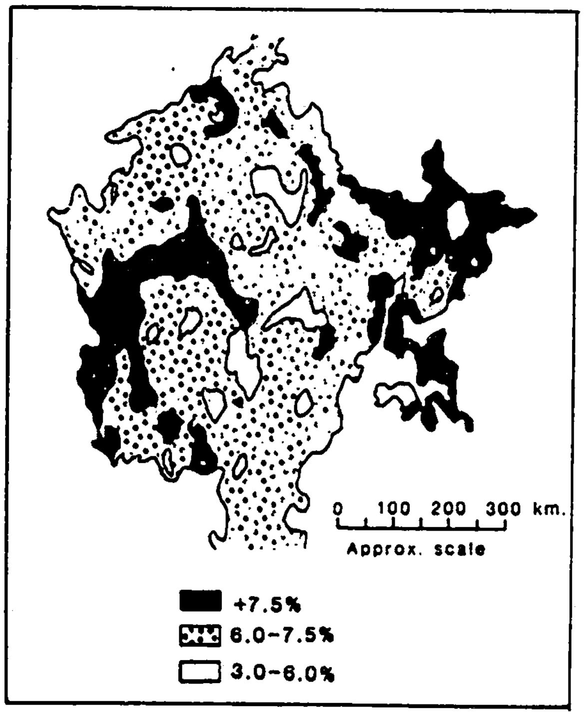


Figure 12. Inferred titanium content of regolith of Mare Tranquillitatis.

Fig. 10. Inferred variations in TiO_2 content of regolith of Mare Tranquillitatis, based on an enlargement of part of Fig. 2 and on the color difference photograph by Johnson et al. (1977).

Table 11

Minable Regolith and Helium Content of Mare Tranquillitatis

Regolith Category	Area in km^2	Average He Content wppm	Regolith Minable tonnes	He tonnes	^3He tonnes
A	84,000	38	252×10^9	9.58×10^6	3,635
B	195,000	25	598×10^9	14.96×10^6	5,754
Totals	279,000		850×10^9	24.54×10^6	9,439

Note: ^3He content based on $He/^3He = 2600$.

LUNAR BASED ASTRONOMY

ASTRONOMY USING A COMMON LUNAR LANDER

JACK O. BURNS, New Mexico State University
STEWART W. JOHNSON, BDM International, Inc.
THOMAS WILSON, NASA/JSC
RUSS GENET, AutoScope
DAVID TALENT, NASA/C-23

ADVANTAGES OF THE MOON FOR ASTRONOMY

In many ways, the Moon is a nearly ideal location from which to perform astronomical observations (Burns and Mendell, 1988; Mumma and Smith, 1990; Burns *et al.* 1990). It is particularly well suited for high resolution imaging and for observations outside the Earth-based windows especially at very low radio frequencies and in the infrared. Some particular advantages of the lunar surface as a site for the next generation of telescopes include:

Low Atmospheric Optical Depths

The average density of the Moon's atmosphere is $0.2 - 1.0 \times 10^6$ molecules cm^{-3} (night to day) which translates to extremely low optical depths at all parts of the electromagnetic spectrum (Potter and Morgan, 1988). In fact, the atmospheric density on the lunar surface is less than that in low Earth orbit. The entire mass of the atmosphere of the Moon is only 10,000 kg, or about that inside a typical basketball arena on Earth. Ninety-three percent of the lunar atmosphere is composed of Ne, H_2, and He (Hoffman *et al.* 1973). There is a similarly low ionospheric density with an estimated plasma frequency of < 90 kHz.

The lack of atmosphere also means, of course, that there will be no wind loading or weather-related problems with lunar-based telescopes. This, coupled with the low gravity, implies that much lighter-weight structures and simpler drive mechanisms would suffice for telescopes on the Moon in comparison to those on Earth.

Seismic Stability

One of the most important advantages of the Moon for astronomy is the excellent seismic stability of the surface. Average ground motions are < 1 nm. Typical subsurface seismic energy is 10^{-8} of that on the Earth (Goins *et al.* 1981). Although moonquakes were recorded during the Apollo program, they are very low level averaging 1-2 on the Richter scale and are much less frequent than on Earth (500/yr vs. 10,000/yr on Earth). The rubble which makes up the subsurface layers of the Moon is an excellent damping agent that does not permit the seismic waves to propagate to the same kind of distances as on Earth. Seismic waves are intensely scattered so the damaging effects of a moonquake are less than those of a similar magnitude quake on the Earth.

The seismic stability is an important issue when considering interferometry at submillimeter, infrared, and optical wavelengths. The baselines between elements in an interferometric array must be controlled to within a fraction of a wavelength to maintain phase coherence. In principle, this can be done in Earth-orbit for short baselines (hundreds of meters) using structures which physically connect array elements. However, for longer baseline interferometry (kilometers) at very high frequencies, maintaining the baselines for free-flying elements requires very complex and very expensive station-keeping. Such baseline stability comes for free on the surface of the Moon where baselines of 10-km or more are feasible and limited only by the curvature of the Moon (Burke, 1990; Burns *et al.* 1991). Thus, the Moon is realistically the only location where very high resolution (tens of *μarcsec*) imaging at optical/IR wavelengths will someday be feasible.

Low Gravitational Field

The surface gravity of the Moon is 162.2 cm s^{-2} or about one-sixth that of Earth. At first glance, any gravitational field might appear to be a disadvantage because of the gravity loading that it would produce on telescope superstructures. However, one must keep in mind the low intensity of the field relative to Earth. The lack of weather plus the low gravity will permit both very large and very "flimsy" telescope support structures on the Moon (Akgul *et al.* 1990; Chua *et al.* 1990). Thus, telescopes of 16-m diameter at optical/IR wavelengths and 1-km diameter for Arecibo-style lunar crater radio antennas become feasible. The Moon offers no practical limit to large aperture telescopes. In fact, one would not likely consider building single aperture structures anywhere much larger than those noted above since interferometers will be more cost-effective in both sensitivity and resolution beyond this point.

The Moon's gravity does have a practical advantage in terms of engineering and construction. It was demonstrated from a combination of the Space Shuttle and the Apollo programs that performing construction activities on the Moon is far simpler (although still nontrivial) in comparison to Earth orbit. The gravitational field of the Moon offers a simple yet important assist for tasks such turning a wrench where the inertial mass of the Moon comes into play. The lunar surface is an environment similar to the Earth in terms of construction activities so that adaptations of familiar Earth-based bulldozers, trenchers, etc. can be used. The pointing system of a lunar-based telescope will use a gravity-assisted mechanical system like that of Earth-based telescopes rather than the complex gyro system on HST.

Large Surface Area

The Moon has large flat areas especially within the maria which are ideally suited for long baseline, high resolution interferometers at submillimeter through optical wavelengths.

The Lunar Far-Side: A Dark and Radio-quiet Sky

At night on the far-side of the Moon, astronomers will have the darkest and coldest skies in the near-Earth environment. Backgrounds will be limited by zodical light, the density of stars near the Galactic plane, and the density of galaxies at high latitudes.

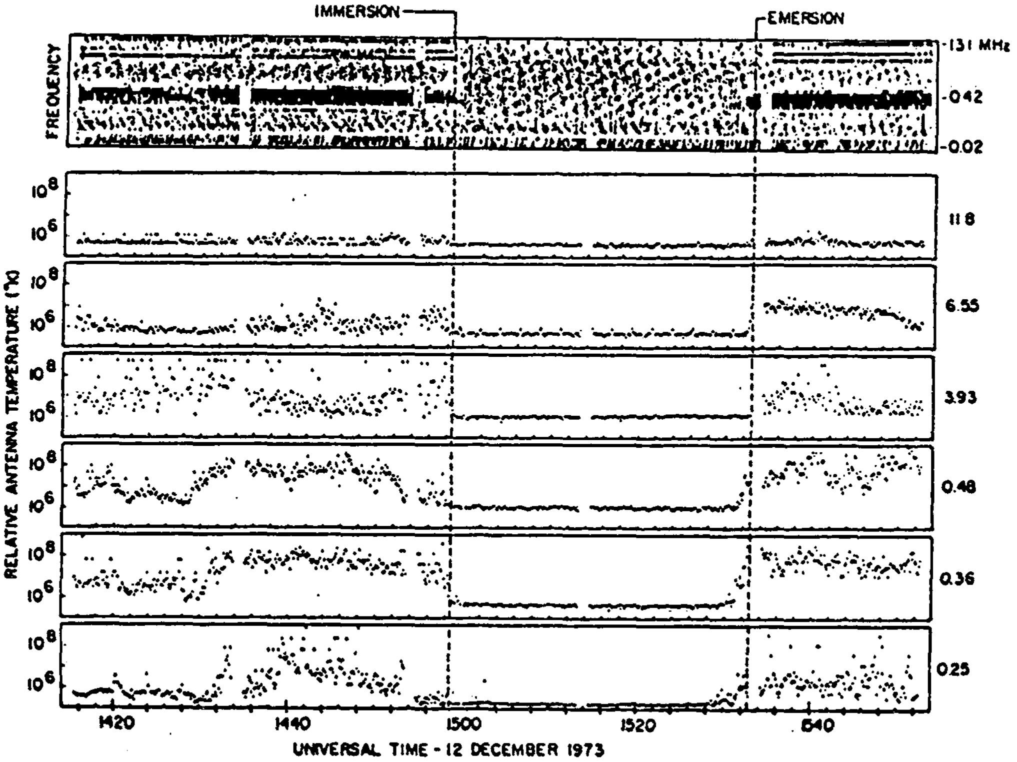


Figure 1. Radio light curves from RAE-2 showing the dramatic difference in low frequency backgrounds on the lunar near-side and far-side (Alexander *et al.* 1975).

The lunar far-side is unquestionably the quietest location at radio frequencies within the inner solar system (Kaiser, 1990). In 1972, a Radio Astronomy Explorer satellite (RAE-2) carrying an enormous V-shaped antenna was placed into lunar orbit (Alexander *et al.* 1975). As shown by Fig. 1, a dramatic reduction in radio frequency background was observed when the Moon occulted the Earth, dropping to near that expected for the nonthermal Galactic emission. The variation between the near and far sides of the Moon becomes even more dramatic at frequencies below a few MHz. Astronomical observations on the Earth at frequencies $\lesssim 30$ MHz have become increasingly difficult because of the irregular and partially opaque (or totally opaque at $\lesssim 10$ MHz, the ionospheric plasma frequency) ionosphere which varies with solar cycle, and because of the increasing man-made interference. RAE-2 has shown that significant man-made interference breaks through the ionosphere especially above 5 MHz on the night-side making observations from Earth-orbit difficult (Erickson, 1990). In fact, LaBelle *et al.* (1989) claim that interference at 5 MHz observed in Earth orbit has increased by a factor of 100 over the past twenty years possibly due to new over-the-horizon radar installations. Lightning storms represent an additional source of interference above a few MHz. Below ≈ 1 MHz, the Earth's magnetosphere is a tremendous source of naturally-produced low frequency emission termed the Auroral Kilometric Radiation (AKR). The AKR, which was the most important discovery of RAE-2, is still not well understood but is likely produced by magnetic field reconnection events in the magnetotail. The only location where one can escape with assurance from these high Earth backgrounds is the lunar far-side.

Natural Cryogenic Environment in Lunar Polar Craters

There are craters near the lunar poles that are permanently shadowed and may have surface temperatures as low as 40 K (Burke, 1988). Such a cold environment would be ideal for siting a telescope which operates in the thermal infrared where both the detector and the telescope superstructure could be passively cooled (Lester, 1988).

Raw Materials

One should not forget that the Moon is rich in raw materials such as aluminum, ceramics, and an interesting high tensile strength, low thermal expansion anhydrous glass (Blacic, 1985). Such materials will be mined from the Moon and potentially used as components for telescope construction, thus greatly reducing costs associated with transportation (e.g., Johnson and Wetzel, 1990). This will eventually become a major advantage over high Earth orbit in siting observatories.

CONCERNS WITH THE LUNAR ENVIRONMENT

Although the environment on the lunar surface offers many substantial advantages over the Earth's surface or in Earth orbit, there are some significant concerns that should be considered. These include:

Cosmic Radiation

No magnetic field is currently being generated within the core of the Moon, so only a very low field is present on the lunar surface. The lunar B-field strength ranges from $3-330\times10^{-5}$ G, which should be compared to an average Earth field of 0.3 G (Dyal *et al.* 1974). Thus, there is little or no modulation of cosmic rays. High energy particles strike the lunar surface unimpeded. This is a considerable problem for both lunar astronauts and for sensitive solid state devices such as CCD cameras.

Fortunately, the lunar regolith (or soil) is an excellent source of shielding for most Galactic cosmic rays. This regolith is mostly powder, having been impacted by micrometerorites over billions of years (Heikien, 1975). It has been estimated that about 5 m of lunar soil would produce a reduction in the flux of cosmic rays equivalent to that in low Earth orbit (Johnson and Dietz, 1991). So, one can envision placing CCDs and other sensitive detectors below the lunar surface in a Coudé room. Alternatively, anticoincidence devices, similar to those used commonly in high energy astrophysics, would need to be developed to remove the effects of cosmic rays as a major source of enhanced background.

Micrometeoroids

The lack of atmosphere means that solar system debris particles strike the Moon's surface with speeds of 10-200 km s^{-1}. From studies of lunar rocks, Taylor (1988) calculates that 1 μm sized craters will be produced by micrometeorites at a rate of 1200 craters $m^{-2}yr^{-1}$. This flux is less than that for low Earth orbit where man-made debris is quickly becoming a major hazard. The lunar micrometeoroids will not produce significant damage to optical surfaces, but the secondary ejecta are potentially very damaging to a telescope (MSFC, 1991). Thus precision optical surfaces may need to be shielded on the Moon.

Thermal Changes

At the Apollo 17 site, day to night surface temperatures ranged from 384 K to 102 K (Keihm and Langseth, 1973). Just below the surface at a depth of 30 cm, the temperature is about 250 K and varies by only 2-4 K from day to night due to the low thermal conductivity. Such large surface temperature variations will place severe constraints on telescope structures which are required to maintain precise tolerances for high resolution imaging. Sunshades and/or metal-matrix composite materials with low coefficients of thermal expansion will be required for the telescope superstructure (Akgul *et al.* 1990).

These temperature variations are severe but are still not as troublesome as in low Earth orbit where spacecraft move in and out of sunlight every 45 minutes. On the Moon, there is two weeks of nearly constant temperature day and two weeks of very cold night. These long periods of thermal stability, especially during the lunar night, will offer astronomers a unique opportunity for stable, deep, and long duration exposures of celestial objects.

Pollution Near a Lunar Outpost

There are ambitious plans for mining, manufacturing, habitats, and spacecraft landings which will potentially vent large quantities of gas into the lunar atmosphere. The lunar vacuum is a fragile commodity as demonstrated by the Apollo program where the mass of the Moon's atmosphere was temporarily doubled during each mission to the Moon (Johnson, 1971). Fortunately, the lunar environment is relatively efficient in cleansing itself of such gas via thermal escape, adsorption by the regolith, and extraction of gas (photoionized by solar uv-radiation) by the solar wind. However, Vondrak (1974) has suggested that significantly higher injection rates, as might result from a vigorous lunar base, could eventually change the loss mechanism to thermal escape alone leading to the development of an atmosphere with a decay rate of hundreds of years. Our own calculations suggest that gas is more effectively dispersed near a lunar outpost (Fernini *et al.* 1990). Assuming a collisionless, isothermal atmosphere, we found that even for the most extreme scenario involving the extraction of large quanitites of He^3 (for fusion reactors on Earth) from the regolith, the density of atmospheric gases drops back to near the present ambient value beyond about 10 km from the mining operation. Thus, we propose that lunar observatories should be sited, and remotely operated, at least this distance from the base. However, the Moon's atmosphere should be measured early in a lunar program to confirm the above models and to determine what, if any, precautions are needed for future telescopes.

Dust is a more troublesome issue. The anhydrous soil is apparently highly susceptible to electrostatic and photoconductivity effects. The Apollo astronauts reported problems associated with charged dust clinging to spacesuits and interfering with the operation of the lunar rover (Neal *et al.* 1988; Johnson *et al.* 1991). In addition, Criswell (1972) noted a bright glow photographed by Surveyor 7 which he attributed to levitation of dust grains at dawn. There is some suspicion that dust "creeps" between light and dark areas due to the establishment of large electrostatic potential differences between these different regions (De & Criswell, 1977). Clearly, more theoretical calculations, laboratory experiments, and early in-situ measurements from the lunar surface are needed to determine the full extent of the dust problem and to propose solutions for lunar-based telescopes.

PROPOSED LUNAR-BASED TELESCOPES

With the above characteristics in mind, we settled upon six concepts for possible astronomical payloads using an unmanned Common Lunar Lander (CLL). Most of the proposed telescopes have masses $\lesssim 500$ kg and modest power requirements. Most of the telescopes would be fully functional upon deployment at the Moon while a low frequency interferometer would operate using multiple sitings. All the telescopes could operate effectively from the lunar near-side although a low frequency array would benefit from a far-side location. Several of these telescopes could be carried to the Moon on a dedicated CLL or single telescopes could be soft-landed as part of a more diverse CLL science payload. The flexibility, modest spacecraft requirements, and strong scientific capabilities of these CLL telescopes make them among the most promising science instruments for the Common Lunar Lander. A summary of recommended telescopes for the CLL program is given in Table 1.

Dedicated, but generic one-meter aperture telescopes hold much promise for early deployment on the Moon (Smith, 1990; Sykes *et al.* 1990). They will likely have masses $\lesssim 200$ kg, will be relatively low power consumers (≈ 100 W), and will be remotely controlled from Earth using the technologies shown feasible by current Earth-based robotic telescopes. Although modest in aperture compared to say HST, they are powerful if dedicated to selected tasks. For example, a lunar automatic photoelectric telescope has the advantage of very high speed and the collection of ungapped data which are so important in testing models of both active stars and galaxies (Zeilik, 1988). An all-sky CCD survey in the uv and the IR using a Schmidt wide-field telescope could be the lunar analog of the tremendously useful Palomar Sky Survey.

The Lunar Transit Telescope (LTT) proposed by McGraw (1990) has the enormous advantage of simplicity. With few moving parts, it is less susceptible to failure on the lunar surface. The LTT maintains a constant elevation pointing and thus monitors a narrow strip of the sky each lunar day. This telescope produces a deep image of the sky strip at several broadband wavelengths ranging from 0.1 to 2 μm. It has diffraction limited imaging in the infrared and ≈ 0.1 arcsec resolution in the visible. During the lifetime of the LTT, the survey would cover about 2% of the sky with multiple observations. The scientific program could include imaging distant galaxies, studying the evolution of galaxies and galaxy clusters, monitoring the variability of active galactic nuclei and quasars, searching for brown dwarf stars, measuring very accurate parallaxes for Galactic stars, and searching for comets in the Kuiper belt (McGraw and Benedict, 1990).

Table 1. Modest Lunar-Based Telescopes

Telescope	Reference
Generic One-meter Telescopes	
- Lunar APT	1, 2, 3
- uv, IR Sky Survey	2
- uv Spectroscopic Telescope	
- Far-IR Testbed	2
Lunar Transit Telescope	4, 5
Lunar Polar Crater Telescope	6
Lunar Hubble Telescope	7
Moon-Earth VLBI	8
Very Low Frequency Interferometers	9

[1]Zeilik (1988)
[2]Sykes et al. (1990)
[3]Genet (1991)
[4,5]McGraw (1990, 1991)
[6]Lester (1988)
[7]Wilson (1990)
[8]Burns & Asbell (1987)
[9]Burns (1991)

Although its power consumption is comparable to the generic 1-m telescopes, a > 2-m aperture mirror would require more lander payload capacity ($\gtrsim$500 kg).

As noted above, some lunar polar craters appear to be permanently shadowed with extremely cold surface temperatures. Lester (1988) has proposed placing a roughly 1-m or larger aperture telescope within such a crater that would operate in the thermal infrared part of the spectrum. The superstructure, mirror, and detectors on such a telescope must all be cooled if one is to lower the background to the theoretical limit given by zodiacal scattered light. The weight of this IR telescope can be greatly reduced (and made comparable to the generic 1-m telescopes above) if the environment can be used to passively cool the telescope. Thus, a lunar polar crater is an ideal environment. The mass and power required are comparable to those for the 1-m telescopes. The difficulty, of course, is landing the CLL inside these craters. Thus, the mission constraints may be more rigorous than some of the other astronomy payloads but the benefits are great. There would also be an impetus to go to a polar crater from a lunar geophysical point of view -- to search for water ice, for example, as some have speculated may exist in these pristine craters.

Another interesting possibility for a CLL astronomical experiment is to use an existing spare 2.2-m mirror originally made for the Hubble Space Telescope (HST) program. This mirror is without the spherical aberration that currently limits HST. Wilson (1990) has suggested that such a very accurate mirror could be made into a very cost-effective telescope on the Moon.

At microwave radio frequencies, an early telescope for the lunar surface may be a Moon-Earth Radio Interferometer (MERI, Burns 1988). We envision an experiment analogous to that performed by the JPL group using the TDRSS satellite and the NASA Deep Space Tracking Network antennas (Levy *et al.* 1986). They demonstrated the viability of space-based very long baseline interferometry (VLBI) by detecting fringes on several quasars for baselines ranging from the Earth's surface to Earth orbit. Similarly, one could use either a dedicated VLBI antenna or a communications antenna coupled with current hydrogen maser clocks to form a VLBI station on the Moon. One could then attempt to detect fringes on baselines of 384,000 km (10 *μarcsec* resolution at 10 GHz) or about 50 times longer than current ground-based VLBI. There may even be a possibility of imaging strong sources at these resolutions since the combination of the American VLBA, the Japanese VSOP low Earth orbit VLBI satellite, the Soviet RadioAstron high Earth orbit antennas, and the lunar antenna produce quite reasonable u-v coverage (Burns and Asbell, 1987).

A further exciting CLL candidate for an early experiment involves very low frequency radio astronomy. Low frequency lunar-based telescopes have the considerable advantages of extremely low mass ($\lesssim$20 kg), low power ($\approx$20 W), and strong scientific motivation. We propose to place low frequency antennas aboard several different CLLs. Interferometry between the CLL antennas can then be performed. For antennas placed widely across the lunar surface and operating at 25 MHz, the resolution of the interferometer can be $\approx$ 2 arcsec (limited by interplanetary scintillation). This resolution, > 100 times better than the best ground-based observations, would place low frequency radio astronomy on a par with centimeter-wavelength astronomy for the first time. Depending on the number and distribution of antennas, imaging at this resolution may be possible. For example, coupling several Moon-based antennas with one attached to a lunar orbiter (communications satellite, for example) at 100-km altitude produces excellent synthetic aperture coverage over timescales of 1 yr. Such coverages result in impressive, well-resolved imaging of 3C-like sources at low frequencies (Burns, 1991). We propose that the antenna on each spacecraft is actually a phased array of > 100 dipoles which are encoded on the surface of an inflatable structure. This unique telescope has good antenna directivity, and will accurately point without any moving parts by electronically phasing the dipole array. A CLL low frequency interferometer offers much scientific promise to investigate fundamental questions involving low energy relativistic electrons including types II and III solar flares, planetary magnetospheres, interstellar medium turbulence, and extragalactic radio sources (Kassim and Weiler, 1990).

An artist's sketch of three of the above candidate lunar-based telescopes on board an unmanned lunar lander is shown in Fig. 2.

SUMMARY

Existing terrestrial robotic telescopes, as well as the proposed South Polar observatories, are crucially important precursors for lunar-based telescopes. The fact that such complex automated telescopes are successfully operated by small staffs at individual observatories gives us hope that similar initially modest lunar-based telescopes on Common Lunar Landers can be built cheaply and operated by small groups back on Earth. It is not necessary to build large and costly institutes to run some of these simple observatories on the Moon. The International Ultraviolet Explorer telescope, operated by several modestly-staffed institutions, is an excellent model for early lunar-based observatories. Such a cost effective management structure, for both the CLL and the telescopes, will be required if we are ever to see observatories on the Moon given the country's on-going fiscal crisis.

Finally, in addition to the promise of important research to come from CLL telescopes, we should not overlook benefits to education. If the CLL program is kept small and tightly managed as suggested above, with direct control of experiments from university laboratories using modern computer technology, then students in high schools and universities can potentially have direct access to the lunar observatories. Such hands-on experience with the modest Moon-based telescopes will both motivate a new generation to pursue research careers in science (as did the Apollo program) as well as build a constituency for a permanently manned lunar base. These telescopes are simple enough and the astronomical observations/goals are accessible so that a broad cross section of beginning to advanced students can participate in this program. Thus, the CLL astronomy program can have wide-ranging effects on research, education, and furthering the American space program.

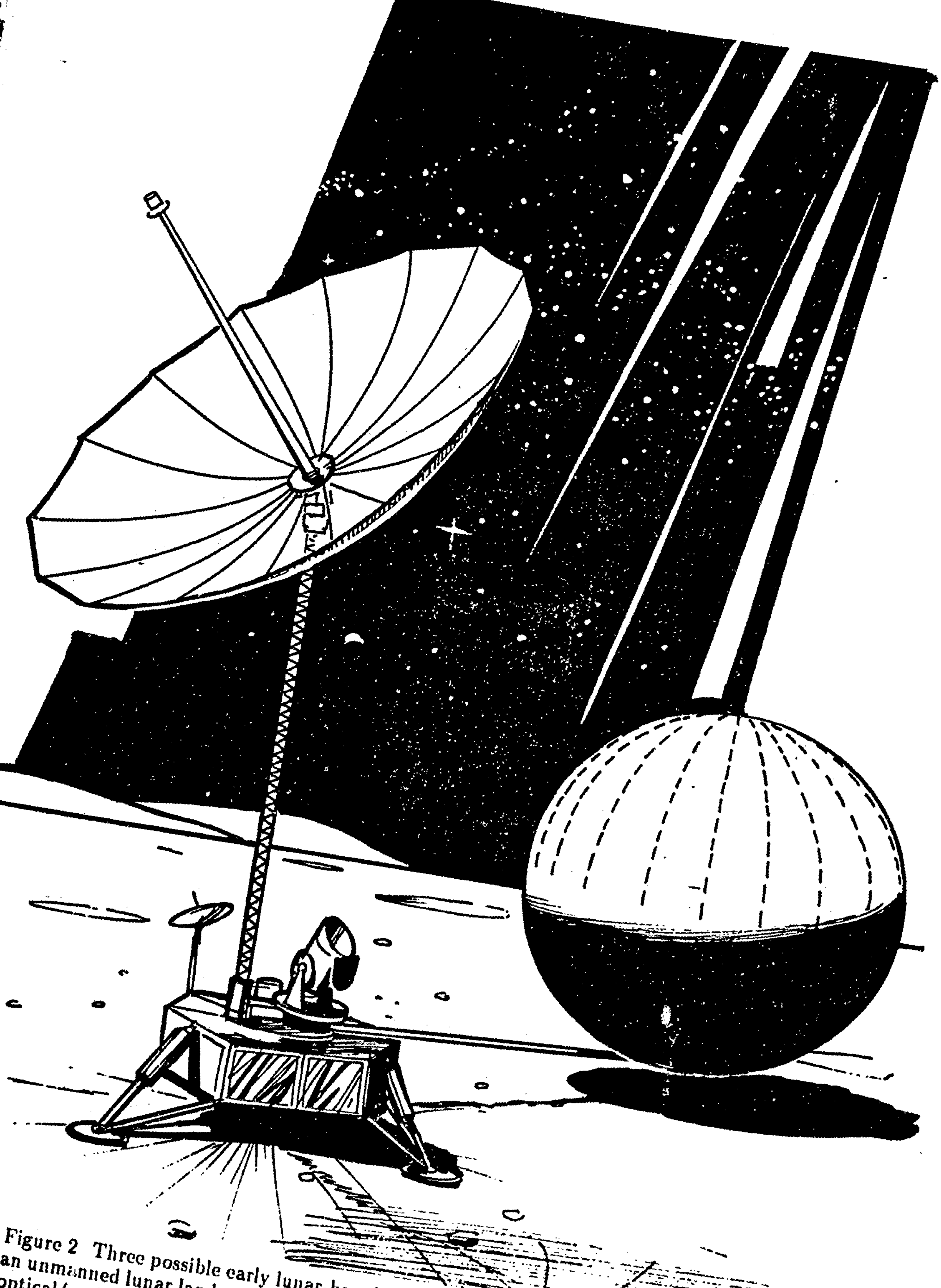


Figure 2 Three possible early lunar-based telescopes placed on the Moon using an unmanned lunar lander. The three telescopes include a VLBI antenna, a 1-m ptical/uv/IR telescope, and an inflatable low frequency phased dipole array ntenna. Drawing is by Pat Rawlings of SAIC.

REFERENCES

Akgul, F., Gerstle, W., and Johnson, S. 1990, in *Engineering, Construction, & Operations in Space, Space 90*, eds. S. Johnson & J. Wetzel (ASCE: NY), p. 697.

Alexander, J., Kaiser, M., Novaco, J., Grena, F., and Weber, R. 1975, *Astr. Ap.*, **40**, 365.

Blacic, J. 1985 in *Lunar Bases & Space Activities of the 21st Century*, ed. W. Mendell (LPI: Houston), p. 487.

Burke, J.D. 1988 in *Future Astronomical Observatories on the Moon*, NASA Conference Publication 2489, eds. J. Burns & W. Mendell, p. 31.

Burke, B. 1990, *Science* **250**, 1365.

Burns, J. and Asbell, J. 1987 in *Radio Astronomy From Space*, ed. K. Weiler (NRAO: Green Bank), p. 29.

Burns, J. and Mendell, W., eds. 1988, *Future Astronomical Observatories on the Moon*, NASA Conference Publication 2489.

Burns, J. 1988, *IBID*, p. 97.

Burns, J., Duric, N., Taylor, G., and Johnson, S. 1990, *Scientific American* **262**, 42.

Burns, J., Johnson, S., and Duric, N., eds., 1991, *NASA Conference Publication*, in press.

Burns, J. 1991 in *Radio Interferometry - Theory, Techniques, & Applications*, ed. T. Cornwell, *A.S.P. Conference Series*, in press.

Chua, K., Hicks, J., and Johnson, S. 1990 in *Engineering, Construction, & Operations in Space II, Space 90*, eds. S. Johnson & J. Wetzel (ASCE: NY), 697.

Criswell, D. 1972, *Proc. Lunar Sci. Conf. 3rd*, 2671.

De, B. and Criswell, D. 1977, *J. Geophys. Res.* **82**, 999.

Dyal, P., Parkin, C., and Daly, W. 1974, *Rev. Geophys. Space Phys.* **12**, 568.

Erickson, W. 1990 in *Low Frequency Astrophysics from Space*, eds. N. Kassim & K. Weiler (Springer-Verlag: NY), p. 59.

Fernini, I., Burns, J., Taylor, G., Sulkanen, M., Duric, N., Johnson, S. 1990, *J. Spacecraft and Rockets* **27**, 527.

Goins, N., Dainty, A., and Tuksoz, M. 1981, *J. Geophys. Res.* **86**, 378.

Heikien, G. 1975, *Rev. Geophys. Space Phys.* **13**, 567.

Hoffman, J., Hodges, R., and Johnson, F. 1973, *Proc. Lunar Sci. Conf. 4th*, 2865.

Johnson, F. 1971, *Rev. Geophys. Space Phys.* **9**, 813.

Johnson, S. and Wetzel, J., eds. 1990, *Engineering, Construction, & Operations in Space II, Space 90* (ASCE: NY).

Johnson, S., Chua, K., Burns, J., and Slane, F. 1991, in *OE/Aerospace Sensing, SPIE Proceedings*, Vol. **1494**, in press.

Johnson, C. and Dietz, K. 1991, *IBID*.

Kaiser, M. 1990, in *Low Frequency Astrophysics from Space*, eds. N. Kassim & K. Weiler (Springer-Verlag: NY), p. 3.

Kassim, N. and Weiler, K. 1990, *IBID*.

Keihm, S. and Langseth, M. 1973, *Proc. Lunar Sci. Conf. 4th*, 2503.

LaBelle, J., Treuman, R., Boehm, M., and Gewecke, K. 1989, *Radio Science*, Nov. 1989, 730.

Lester, D. 1988 in *Future Astronomical Observatories on the Moon*, NASA Conference Publication 2489, eds. J. Burns and W. Mendell, p. 85.
Levy, G. *et al.* 1986, *Science* **234**, 187.
Marshall Space Flight Center (MSFC) Study 1991, *Large Lunar Telescope.*
McGraw, J. 1990, in *Astrophysics from the Moon*, eds. M. Mumma & H. Smith (AIP: NY), p. 433.
McGraw, J. and Benedict, G. 1990, *IBID*, p. 464.
Mumma, M. and Smith, H., eds., 1991, *Astrophysics from the Moon* (AIP: NY).
Neal, V., Shields, N., Carr, G., Pogue, W., Schmitt, H., and Schulze, A. 1988, *Extravehicular Activity at a Lunar Base, Phase II Final Report*, NASA NAS9-17779, p. 41, 62, 70.
Potter, A. and Morgan, T. 1988, *Science* **241**, 675.
Smith, H. 1990, in *Astrophysics from the Moon*, eds. M. Mumma & H. Smith (AIP: NY), p. 273.
Sykes, M. *et al.* 1990, *IBID*, p. 328.
Taylor, G. 1988, in *Future Astronomical Observatories on the Moon*, NASA Conference Publication 2489, eds. J. Burns & W. Mendell, p. 21.
Vondrak, R. 1974, *Nature* **248**, 657.
Wilson, T.L. 1990, *Nature* **346**, 310.
Zeilik, M. 1988, in *Engineering, Construction, & Operations in Space I, Space 88*, eds. S. Johnson & J. Wetzel (ASCE: NY), 1095.

Southwest Ultraviolet A[illegible]ical/Atmospheric Telescope (SW[illegible]T)

Alan Stern (Southwest Research Institute)
Southwest Research Institute

01 July 1991

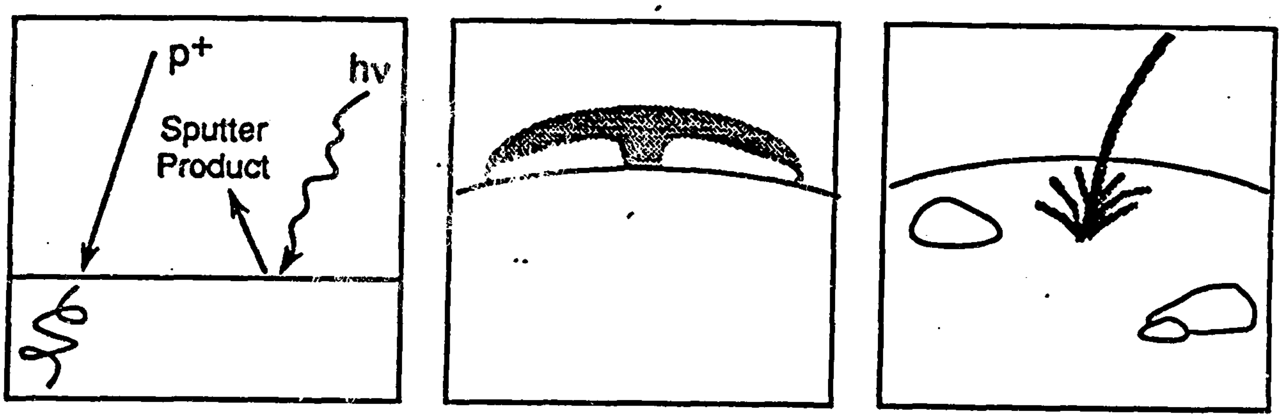
Characteristics of the Lunar Atmosphere	
Surface Number Density	$<10^5 - 10^6$ cm^{-3}
Typical Mean Free Path	$\sim 10^4$ km
Total Mass	$\sim 3 \times 10^4$ kg

Measured Lunar Atmospheric Abundances

Species	Detection Method	Wavelength (Å)	Surface Density (cm^{-3})	
He	Mass Spectrometry	584	1×10^3	[day]
			4×10^4	[night]
Ar	Mass Spectrometry	1048	1.6×10^3	[day]
			4×10^4	[night]
Na	Groundbased	5890, 5896	67 [day]	
K	Groundbased	7664, 7699	15 [day]	

The Relation of the Lunar Atmosphere to Lunar Science

- Surface Modification Processes
- Volatiles and Internal Discharges
- Atmospheric Phenomena Relating to Impacts



Volatile Release

Impact

The Role of Atmospheric Investigations in Lunar Observer Geoscience

- Atmospheric Investigations are Likely to be the Best Way to Determine if Volatile Reservoirs Exist.
- Atmospheric Investigations Directly Bear on Surface/Regolith Composition Differences and Weathering Due to the Space Environment.
- Ion/Plasma Studies Play an Important Role in Determining if a Lunar Core Exists and in Local Magnetic Structures Data.
- Atmospheric Investigations Determine the Degree of Radiogenic and Juvenile Outgassing.
- Atmospheric Investigations are Likely to be the Only Definitive Way LO can Detect Present-Day Lunar Activity.

The Precursor Role of Atmospheric Investigations for the Lunar Outpost

- Document the Lunar Atmosphere and Surface Weathering Environment Before it is Corrupted.
- Atmospheric Investigations Document the Lunar Environment Humans and Equipment Must Survive In.
- Key Discoveries, such as the Detection of Volatile Reservoirs or Sites of Indigenous Activity Can Affect Outpost Site Selection.
- Atmospheric Investigations Bear Directly on Payload Design for Future Surface Instrument Networks and Astronomical Facilities.

Table 2

Rationale for Lunar Atmospheric Studies

- Because of Intrinsic Interest in the Lunar Environment and Lunar Processes
- Because Atmospheric Studies Play an Important Role in Understanding:
  - Surface Modification and Weathering
  - Volatile Discharges
  - Internal Outgassing and Activity
  - Internal Structure and Evolution
- To Search for Volatiles, Particularly Water
- To Study Comparative Planetary Exospheres
- Because Doing Lunar Astronomy Requires Understanding the Atmospheric Background
- Because Lunar Exploration and Habitation Will Destroy the Pristine Environment

Table 3

Primary Coupling of Measurement Objectives to Scientific and Operational Rationale for Studying the Lunar Atmosphere						
Rationale / Scientific Objective	Understand the Lunar Atmosphere	Understand Surface Weathering Processes	Study the Lunar Interior and Activity	Provide An Analog to other Tenuous Atmospheres	Locate Volatile Resources	Provide Baseline for Lunar Astronomy
Determine Neutral and Ion Composition	●	●	●	●	●	●
Search for Evidence of Volatiles	●		●		●	
Measure Horizontal Structure and its Temporal Variations	●	●	●	●	●	●
Measure Vertical Structure	●	●		●		●
Identify and Quantify Source and Sink Mechanisms	●	●	●	●	●	
Search for Transient Events	●		●	●	●	●

● = Good

Table 4

Suitability of Observational Vantage Points (by Scientific Objective)				
Measurement Objective	Groundbased	Earth Orbital	Lunar Orbital	Lunar Surface
Determine Neutral and Ion Composition	○	○	●	●
Search for Evidence of Volatiles		○	●	●
Measure Horizontal Structure	○	○	●	
Measure Vertical Structure	○	○	●	○
Measure Temporal Effects	●	●	●	●
Identify and Quantify Source and Sink Mechanisms	○	○	●	●
Search for Transient Events	○	○	●	○

● = Good; ○ = Limited; Blank = very limited or nonexistent.

Table 5

Suitability of Observational Vantage Points by Measurement Requirement				
Measurement Requirement	Groundbased	Earth Orbital	Lunar Orbital	Lunar Surface
Observe Neutral Atmosphere	○	●	●	●
Measure Ionosphere/Plasma Environment			●	●
Detect H_2O, CO, CO_2 Reservoirs		○	●	○
30-50 km Spatial Resolution	●	●	●	N/A
Global Coverage			●	
Measure Vertical Structure	○	○	●	○
Continuous Observations Spanning Many Lunations	●	●	●	●

● = Good; ○ = Limited; Blank = very, limited or nonexistent.

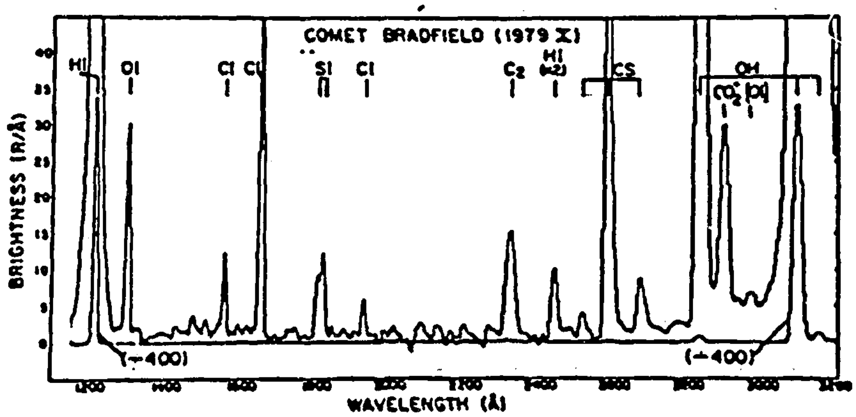
Capability of Experimental Techniques for Directly Accomplishing Measurement Objectives						
Technique / Objective	Total Pressure	Radio Science	Neutral Mass Spectroscopy	Ion Mass Spectroscopy	Optical/UV Spectroscopy	Alpha Particle Spec-troscopy
Measure Neutral Density, Composition			●		●	
Measure Ionosphere/Plasma Density, Composition		○		●		
Detect Outgassing	○		○	○	●	○
Detect H_2O, CO, CO_2 Reservoirs			○	○	●	
30-50 km Spatial Resolution	●	○	●	●	●	○
Global Coverage	●		●	●	●	●
Observe Daytime Atmosphere	●	●	●	●	●	
Observe Nighttime Atmosphere	●	●	●	●		
Measure Vertical Structure		○	○	●	●	

● = Good; ○ = Limited; Blank = very limited or nonexistent.

Why UV Spectroscopy?

No UV Capabilities Presently Planned for LGO
($\lambda < 3500$ Å)

- All Known Lunar Atmospheric Species (He, Ar, Na, K) Can Be Observed in the UV
- Most Atmospheric Candidate Species (e.g., Mg, Ni, Fe, OH, noble gases) Fluoresce in the UV
- OH, H Emissions Are the Best Way to Detect H_2O at Very Low Sublimation Rates
- UV Spectroscopy Can Also Determine Atmospheric
  - Temperatures
  - Emission Mechanisms
  - Ionization Fractions



- UV Spectroscopy Adds Capabilities for Studies of Surface Spectroscopy and Optical Properties by:
  - Preferentially Sampling Surface Coatings
  - Preferentially Sampling Smaller Particles
  - Opening Up Fe-O, Ti-O Absorption Bands

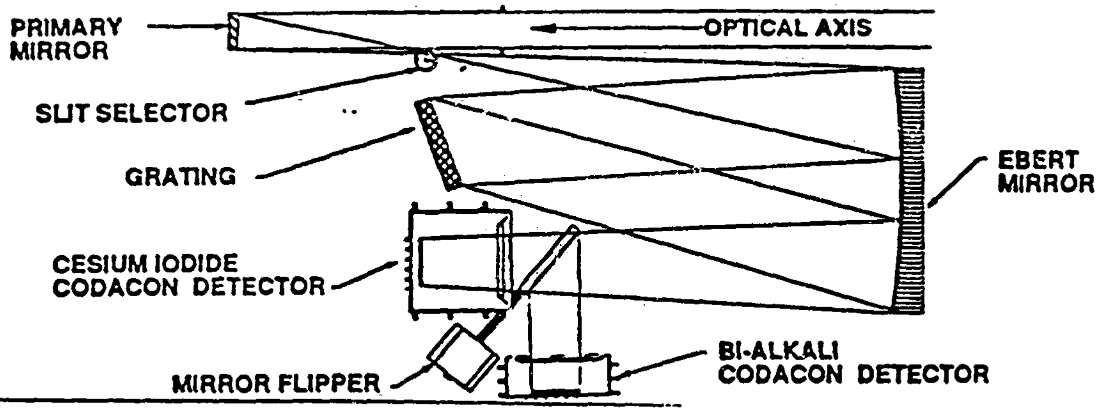


Table 5. LAUS Instrument Characteristics

	UAS	SPMP
Telescope		
Focal Length	100 mm	100 mm
Focal Ratio	F/5	F/10
Aperture	20 mm x 20 mm	10 mm dia
Spectrograph	Plane Grating	Filter
Focal Length	250 mm	
Focal Ratio	F/5	
Grating	Holographic	
Ruling	2400 g/mm	
Blaze Wavelength	3000 Å	
Entrance Slit	0.3 x 10 mm	
Detector	1024-Element CODACONs	PMT
Detector		
G Channel	CsI Photocathode	S1 cathode (tri-alkali)
N Channel	KCsSb Photocathode	
Pixel Size	0.025 x 10 mm	
Wavelength Range	1100-1700 Å 1600-4400 Å	5890 Å (Na) 7665 Å (K)
Resolution (1st order)	5 Å (0.3 mm slit) 1 Å (0.050 mm slit)	1 Å
Instrument		
Field of View	0.17 Degrees	2 Degrees
Off Axis Rejection	10^{10}	10^{5}
Mechanisms	Grating Drive Moveable Window Bi-Stable Slit Altitude Scan Mechanism	None Altitude Scan Mechanism
Power:	10 Watts	
Mass:	10 Kg	
Envelope:	LO compatible	

Table 1. Lunar Atmospheric Abundances

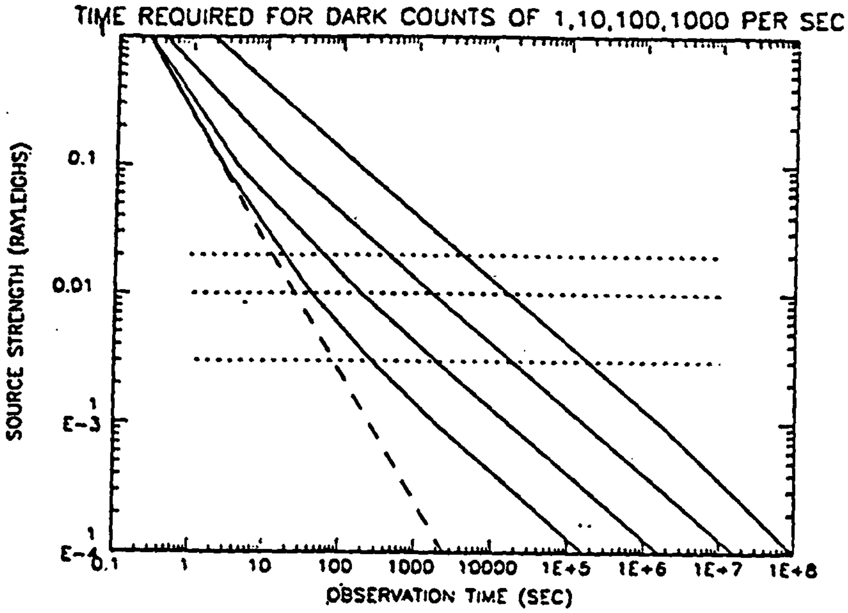
Species	*Energy-State Transition*	*Wavelength Å*	*Observed Density atoms/cm3*
He[b]	$^2S-^2P$	584	1×10^3 [day] 4×10^4 [night]
Ar[b]		869	1.6×10^3 [day] 4×10^4 [night]
H[a]	$^2S-^2P$	1216	<10
O[a]	$^3P-^3S$	1304	<40
C[a]	$^3S-^3P$	1657	<15
N[a]	$^4S-^4P$	1200	<300
Kr[a]	$^1S-^3P$	1236	<10,000
Xe[a]	$^1S-^3P$	1470	<1,000
H_2[a]	$B^1\Sigma_u^+ - X^2\Sigma_g^+$ (6,9)	1462	<6,000
CO[a]	$A^1\Pi - X^1\Sigma^+$ (1,0)	1510	<20,000
Na[c]	$^2P^0-^2S$	5890, 5896	67 ± 12
K[c]	$^2P^0-^2S$	7664, 7699	15 ± 3

[a] Fastie et al. (1973) [b] cf., Hunten (1988) [c] Potter and Morgan (1988)

Table B1.

Species	Wavelength	Mode	Sensitivity photo-electrons sec/R	g-factor photons/sec	Surface* Density cm^{-3}	Observed Brightness R	g-factor, photons/sec	Surface Density cm^{-3}
H	1216	C	75	2.2×10^{-3}	< 10	< 0.01	1.3×10^{-3}	< 17 [a]
O	1304	B	99	2.0×10^{-5}	< 80	< 0.01	4.6×10^{-6}	< 500
N	1200	B	70	3.6×10^{-6}	< 600		3.6×10^{-6}	< 600
C	1657	B	25	2.1×10^{-4}	< 30	< 0.02	1.7×10^{-5}	< 200
Kr	1236	A	85	1.6×10^{-7}	< 20 000		1.6×10^{-7}	< 20 000
Xe	1470	A	75	1.5×10^{-6}	< 2 000	< 0.003	1.5×10^{-6}	< 3 000
H_2	1462	B	75	4.0×10^{-8}	< 12 000	< 0.003	4.0×10^{-8}	< 9 000
CO	1510	B	60	7.5×10^{-8}	< 40 000	< 0.01	1.7×10^{-7}	< 14 000
S[b]	1474	A	75			< 0.003	6.0×10^{-6}	< 150

* Taken from Fastie et al. (1973b).
a Revised from Fastie et al. (1973b).
b Not considered by Fastie et al. (1973b).


TIME REQUIRED FOR DARK COUNTS OF 1,10,100,1000 PER SEC
SOURCE STRENGTH (RAYLEIGHS)
0.1
0.01
E-3
E-4
0.1
1
10
100
1000
10000
1E+5
1E+6
1E+7
1E+8
OBSERVATION TIME (SEC)

ASTRONOMY-ASTROPHYSICS

RATIONALE

- THE MOON IS AN IDEAL PLACE FOR ASTRONOMICAL OBSERVATIONS
  - LACK OF ATMOSPHERE
  - SEISMIC STABILITY
  - SKY AVAILABILITY
  - DARK, COLD SKY
  - ACCESS FOR EMPLACEMENT AND MAINTENANCE
- OPERATION OF ASTRONOMICAL FACILITIES WILL BE DONE REMOTELY FROM EARTH
- LUNAR CREWS WILL INSTALL, MAINTAIN, UPGRADE AND ANALYZE OPERATION OF FACILITIES TO IMPROVE DESIGN CAPABILITIES

Scientific Rationale

- The Moon is the best site for observational astronomy (superior to Earth-Orbit, Mars)
- The Moon is most attractive for conducting high-resolution interferometry in a variety of wavelengths
- Emplacement Phase:
  - Low mass
  - Ease of installation
  - Low maintenance
  - High science return
  - Diversity of Phenomenology covered
  - Long radio baseline with Earth
  - Test-bed for next generation of experiments
- Consolidation and Utilization Phase:
  - Greater facility expense necessitates focussing of effort
  - Science unique to lunar site
  - New techniques (interferometers) utilizing individual components that are well-understood
- Post-Utilization Phase
  - Permanent occupation allows for open-ended expansion of astronomical facilities

Astronomy

DART 4
U.V. TELESCOPE

- IUE is by far the most cost-effective space astronomy instrument ever flown
- The Moon offers opportunity for very-low-cost type of IUE
- Longer lifetime and 2-magnitude fainter limit
- Order-of-Magnitude increase in number of objects accessible
- Invaluable support to HST and relief from its oversubscription pressure

COMMON LUNAR LANDER PAYLOAD DATA SHEET

Payload Name: Southwest Ultraviolet Astronomical/Atmospheric Telescope (SWUAAT)

Purpose of Payload: Lunar Astronomy Testbed/Geophysical Research on Lunar Atmosphere (e.g. detect H_2O, CO, CO_2: Study Na, K, Ar already-detected by Apollo/Groundbased instruments).

Desired Landing Site(s) (Feature Name(s), Lat., Long.,):

Prefer Front Side. Latitude can be equitorial or polar.

Mass ( ): 40 kg

Dimensions -

Length (m): 1

Width (m): 0.4

Height (m): 0.4

Volume (m^3): 0.2

Experiment Duration (days, months, years): Months (daytime ops only)

Experiment Duty Cycle: TBD

Power Profile -

Max. Power (w): 40 W

Setup Power (w): 40 W

Lunar Day Power (w):

Lunar Night Power (w): Heater Loads Only (TBD depending on thermal design, may be very low).

Telemetry -

Uplink (bps): 64

Downlink (bps): 4 kbps

Setup Requirements -

Can Experiment Remain on Lander (y/n)? yes

Should Experiment be Set on Lunar Surface (y/n)? no

Should Experiment be emplaced (drilled or buried) into the Regolith (y/n)? no

How Far does Experiment have to be Setup from Lander (m)? On lander or at any distance if T/M, power are provided by Rover.

Additional Requirements:

NOTE: The SWUAAT payload is based on strong Mariner/Veyager/Spartan/ Galileo heritage. Pointing can be provided by an experimenter-supplied platform if required.

Astronomy

DART 4
U.V. TELESCOPE

- IUE is by far the most cost-effective space astronomy instrument ever flown
- The Moon offers opportunity for very-low-cost type of IUE
- Longer lifetime and 2-magnitude fainter limit
- Order-of-Magnitude increase in number of objects accessible
- Invaluable support to HST and relief from its oversubscription pressure

5.2.9 Ultraviolet Spectrometer (UVS)

5.2.9.1 General Information

Instrument ID: Ultra Violet Spectrometer (UVS)

Science Objectives: Characterize Lunar atmosphere, search for volatiles.

Measurement: Optical spectroscopy at UV wavelengths.

Operating Wavelength: TBS

Description: The UVS Experiment will seek to determine the composition, density, temperature, ionization fractions, and time variation of residual lunar atmospheric constituents. Known atomic species in the residual atmosphere are He, Ar, Na, and K. Candidate species are Mg, Ni, Fe, OH, H, and noble gasses. Production mechanisms such as cometary or meteoric impact, sputtering, or volatile release will be sought by mapping the vertical distribution profile above the lunar limb as the S/C orbits above the surface. The instrument will measure UV emissions of atmospheric constituents stimulated by solar radiation. The instrument needs to sample above the limb at various points along an atmospheric scale height, which varies for different constituents. Thus it must be able to scan from the limb to a height of several hundred kilometers above the surface.

Heritage: This instrument will be based on designs and technology utilized successfully for Voyager, Galileo, Pioneer Venus, and numerous Earth Orbiters. The microchannel plate detector technology is well developed and understood. While an instrument would need to be made from scratch for LO-specific application, it could utilize many existing components available from past instrument development efforts.

5.2.9.2 Operational Modes

Operational Modes:

Mode No. 1: Primary mode - limb studies
Mode No. 2: Occasional calibration on surface/stars (internal instrument pointing)
Mode No. 3: Standby

Coordination With Other Instruments: Mass spectrometers, XRS, GRS, LOIS, VIMS. All required in data analysis, but not requiring simultaneous observing.

Ancillary Data Requirements: S/C attitude, orbit reconstruction, and timing.

Special Calibration Requirements: None

5.2.9.3 Mechanical Characteristics

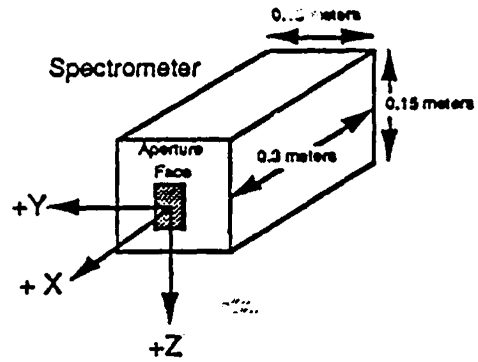
	DIMENSIONS	MASS
Spectrometer (may include baffles, logic, microprocessor, power, and telescope)	0.15 x 0.15 x 0.30 m	7 kg

Instrument mounting can be anywhere on the bus as long as the slit can see the lunar limb without obstruction within ±10 degrees. See section 5.2.9.6 for viewing details. Long axis points in X-direction (can be + or -).

Total Instrument Mass: 7 kg

Mechanical Disturbance: Diffraction Grating, mass = 0.002 kg. Grating motion via a stepping motor is a possible configuration for this instrument, frequency TBD.

UVS Conceptual Drawing



5.2.9.4 Power and Thermal

Operating Power: 10 Watts for data acquisition mode

Standby Power: 3 Watts

Non Operating Power: 3 Watts. Replacement heater may be required.

Survival Power: 3 Watts

Power Duty Cycles: UVS will operate at it's 10 watt data acquisition mode power level whenever the visible atmosphere above the limb is in daylight. This corresponds to about 60% of an orbit during high-sun periods and up to 100% of an orbit during low-sun (terminator) orbits. It will be able to operate the remainder of the time at it's 3 watt standby level.

Thermal Control:

	Operating:	Standby:	Non-Operating:	Survival:
Instrument	0 to 50° C	TBD	TBD	TBD
Electronics	0 to 50° C	TBD	TBD	TBD
Detectors(s):	TBD	TBD	TBD	TBD

Radiator/Cooler: TBD

5.2.9.5 Data and Command

Science Data Rates: 5 kb/s.

Engineering Data Rate: 40 - 200 b/s

Engineering Bit Error Rate: 10^{-6}

Science Bit Error Rate: 10^{-6} (internal data compression)

The instrument will be capable of operating between 2 and 10 kb/s, depending on available bandwidth. As this is packetized, it will be automatically adjusted. A working value of 5 kb/s is adopted for mission planning purposes.

The data rate utilized relates to both vertical and spatial resolution as well as signal-to-noise ratio of the measurements. If regions of unusual data are found, it will be desired to obtain the higher-rate data when the S/C passes over those regions.

5.2.9.6 Viewing and Pointing Requirements

Field-Of-View (FOV):

Aperture Size:	TBD
Aperture Shape:	Rectangular Slit
Viewing:	Lunar Limb
Scan Range:	+/- 10 deg. elevation from limb
Unobstructed FOV:	TBD

Solar Exclusion Angle: > 30 deg. (may be a problem for high-sun orbits, see Issues and Liens)

The scan range requirement is +/-10 degrees from the lunar limb. Since the S/C is at a 100 km (nominal) orbit, the limb will be 19 degrees below the S/C X-axis. For a 70 km orbit, the depression angle to the limb will be 16°, and for a 130 km orbit, the angle will be 21.5°. Thus the available scan range will have to be at least -6 to -32 degrees or more to account for larger orbit altitude dispersions. (-4° to -42° would cover a 50 to 300 km orbit altitude range).

Pointing Requirements:

Pointing Accuracy:	+/- 10 mrad (3 sigma)
Pointing Stability:	3 mrad/sec (0.5 to 1.0 mrad/.5 sec)
Absolute Knowledge:	3 mrad (3 sigma)
Relative Knowledge:	3 mrad/sec (0.5 to 1.0 mrad/.5 sec)

Co-registration Instruments: None

5.2.9.7 Environmental Compatibility

EMI/RFI Susceptibility: TBD

Contamination Susceptibility: No direct thruster impingement on the instrument. The instrument should have Nitrogen purge for launch, and some form of cover.

Magnetic Susceptibility: TBD

EMI Sources: Similar to PVO/Galileo (which means?)

Magnetic Sources: The grating stepper motor will generate some magnetic noise. On Galileo, UVS stepper noise is detectable by the plasma wave detector. On LO, RAE may be affected.

Microphonics: TBD

5.2.9.8 Open Issues and Liens

1) This is a "virtual" instrument as defined herein. Actual specs will not become available until the time AO proposals are received.

2) Solar exclusion angle requirements may not be avoidable during sunrise/sunset periods of high-sun orbits. If instrument design cannot accommodate exclusion angle constraint (e.g. via a boresight offset in the X-Y plane), it will have to be satisfied by instrument operating constraints.

Astronomy

DART 4
U.V. TELESCOPE

- IUE is by far the most cost-effective space astronomy instrument ever flown
- The Moon offers opportunity for very-low-cost type of IUE
- Longer lifetime and 2-magnitude fainter limit
- Order-of-Magnitude increase in number of objects accessible
- Invaluable support to HST and relief from its oversubscription pressure

TECHNOLOGY DEVELOPMENT FOR LARGE LUNAR-BASED OBSERVATORIES: THE ROLE OF THE COMMON LUNAR LANDER

Stewart W. Johnson
Principal Engineer, Advanced Basing Systems
BDM International, Inc.
1801 Randolph Road, S.E.
Albuquerque, NM 87106
Phone (505) 848-4013
Fax (505) 848-5528

Jack O. Burns
Professor and Department Head
Department of Astronomy
Box 30001/Department 4500
Las Cruces, NM 88003
Phone (505) 646-4438

PAPER PRESENTED AT THE WORKSHOP ON THE COMMON LUNAR LANDER
Session on Lunar-Based Astronomy

NASA JOHNSON SPACE CENTER
HOUSTON, TEXAS

July 1st and 2nd, 1991

TECHNOLOGY DEVELOPMENT FOR LARGE LUNAR-BASED OBSERVATORIES: THE ROLE OF THE COMMON LUNAR LANDER

Stewart W. Johnson[1] and Jack O. Burns[2]

INTRODUCTION

The Workshop on the Concept of a Common Lunar Lander, which was held at the NASA Johnson Space Center on July 1 and 2, 1991, discussed potential payloads to be placed on the Moon by a common, generic, unmanned, vehicle beginning late in this decade. At this Workshop a variety of payloads were identified including a class of one-meter (and larger) optical telescopes to operate on the lunar surface. These telescopes for lunar-based astronomy are presented in an earlier section of this report. The purpose of this section is to suggest that these and other payloads for the Common Lunar Lander be used to facilitate technology development for the proposed 16-meter Aperture UV/Visible/IR Large Lunar Telescope (LLT) (Bely et al., 1989; Nein, Davis, et al., 1991) and a large optical aperture-synthesis instrument analogous to the Very Large Array of the National Radio Astronomy Observatory (Burke, 1990; Burns et al.,1990a).

The Bahcall Report (1991) noted that the Moon is an excellent site for the above-mentioned and other astronomical observatories which would there be capable of making significant advances over terrestrial-based and free-flying orbiting telescopes. The Report went on to recommend that "NASA should initiate science and technology development so that facilities can be deployed as soon as possible in the lunar program" and "NASA should develop the technology necessary for constructing large telescopes..."

TECHNOLOGIES

Many technologies are required for establishing these large telescopes on the Moon (Johnson and Wetzel, 1989; Burns et al. 1990b; Illingworth, 1990). Listed below are seven examples of technologies for these large telescopes which we feel deserve attention in planning payloads and operations of the common lunar lander.

---

[1]Principal Engineer, Advanced Basing Systems, BDM Inc., 1801 Randolph Road, S.E., Albuquerque, NM 87106.

[2]Department Head and Professor, Department of Astronomy, New Mexico State University, Box 30001/Dept. 4500, Las Cruces, NM 88003.

1. Geotechnical (e.g., soils, excavation, and foundations).
2. Mitigation of Detrimental Environmental Effects (e.g.,dust).
3. Construction.
4. Contamination/Interference Control.
5. Verification of Stable Precision Structures Performance on the Moon for Telescope Applications.
6. Optical Systems and Their Performance in the Environment.
7. Test and Evaluation of Systems for Lunar Observatories.

We will discuss each of the above listed seven technologies in turn and suggest how their development could be enhanced and accelerated by the common lunar lander program:

1. Geotechnical engineering and associated technologies are required to properly support a large telescope on the lunar regolith, to provide in situ materials for shielding of sensitive telescope components (e.g., charged-coupled devices (CCDs)), and to facilitate site characterization and preparation. It is essential to learn what design limitations are imposed by the strength and load-deformation characteristics of the regolith and its stability in excavations. Much was learned from the Apollo and predecessor programs about the regolith but the engineering information is still incomplete. The regoliths on the airless, dry, lifeless Moon developed from uniquely different processes than those on Earth which formed in the presence of oxygen, wind, water, and a wide variety of life forms. On the Moon the regoliths are formed by the continous impacts of a full range of sizes of meteoroids and incessant bombardment by charged atomic particles from our sun and the stars. Doing geotechnical engineering for the large lunar telescopes will differ substantially from terrestrial applications and the penalty for miscalculation will be immense. We suggest that acquiring the following information be addressed with the lunar lander (Carrier, 1991):

Topographic maps of potential observatory sites (Carrier suggests 10-cm contours over an area 1 km in radius).
Detailed boulder sizes and counts over the same area.
Surveys (e.g., by radar, microwave or other means) for subsurface boulders over critical areas where foundations and excavation are desired.
Surveys of depth-to-bedrock (with suitable definition and characterization of bedrock).
Trenching and bulldozing experiments that establish energy requirements and depth limitations for these operations.
Drilling and coring experiments; with energy consumption and

depth limitations quantified.

Force versus depth cone penetrometer measurements to be used for siting settlement-sensitive telescope structures.

Trafficability measurements including establishing energy consumption, slope climbing capabilities, and formation of ruts or depressed surfaces by repeated traverses of unprepared surfaces.

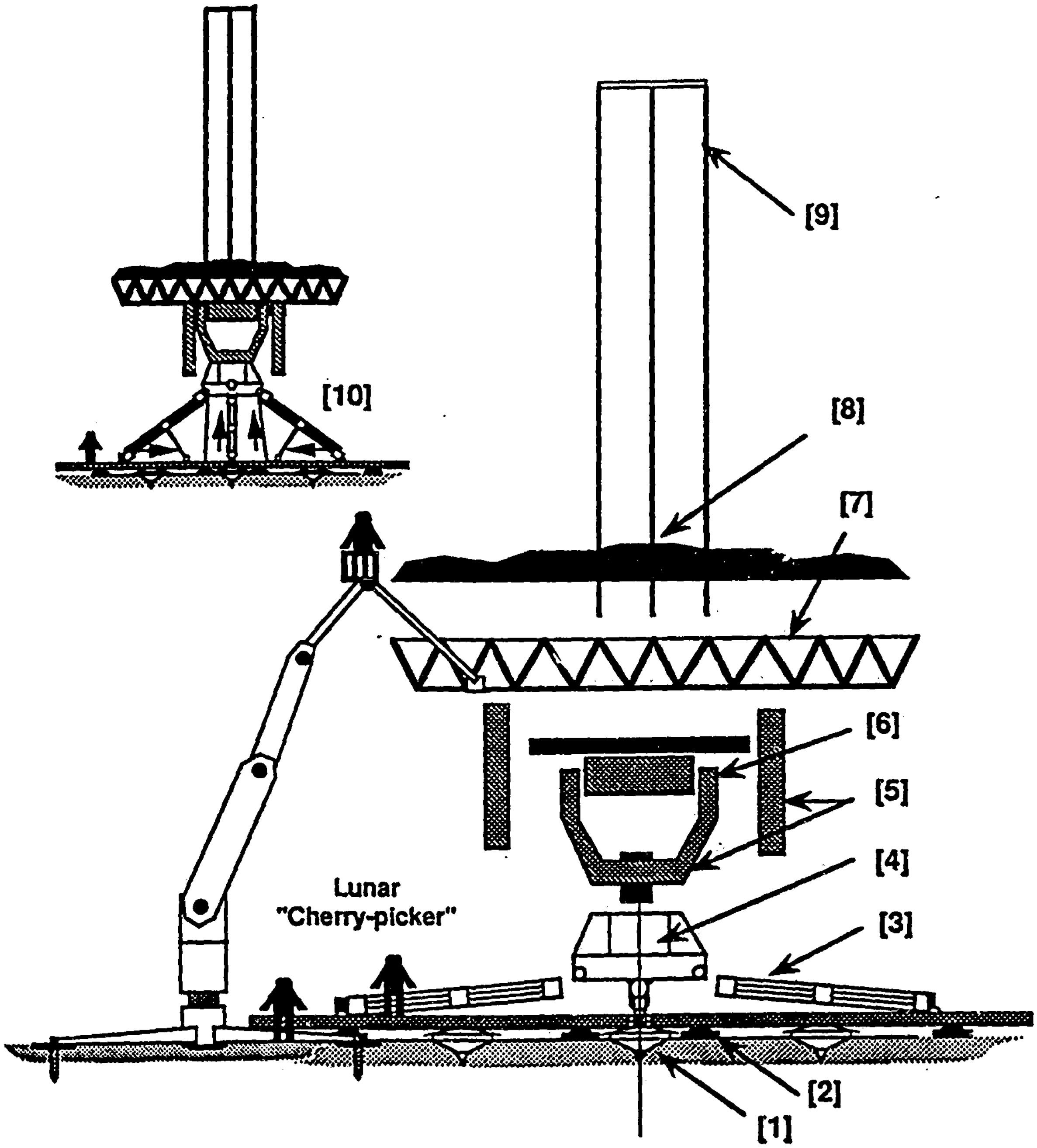
Electrostatic charge measurements.

Some of the above listed needs can be combined with proposed geophysical investigations.

2. Mitigation of detrimental environmental effects including dust (Johnson et al., 1991) can be the subject of investigations using the common lunar lander. Dust transport mechanisms, both natural and equipment-related, should be established by direct measurements. The amount of dust levitated at the day-night terminator as by charge differences built up by photoconductivity effects (Criswell, 1972) should be determined. Predictions of effects of the radiation environment of the lunar surface on telescope components can be verified using common lunar lander components as well as revisits of equipment left on the Moon during the 1960s and 1970s. There is a need to quantify synergistic effects of environmental factors (e.g., vacuum, ultraviolet, micrometeoroid and secondary impacts, thermal cycling, and dust) on component viability. We need to ascertain the long-term effects of the lunar environment on thermal control coatings and polished surfaces. Also needed are ways of using the common lunar lander to validate that drives, vacuum and dust-sealed bearings, and other mechanical components for large lunar telescopes (and construction equipment) will function on the Moon in the presence of dust, radiation, thermal cycling, and vacuum.

3. Construction on the surface of the Moon of a 16-meter telescope and a Lunar Optical/Ultraviolet/Infrared Synthesis Array (LOUISA) will require that the geotechnical engineering and degradation abatement considerations in paragraphs 1 and 2 above be addressed. Information gathered from common lunar lander investigations in these areas will feed directly into answering questions as to how the construction process for the large lunar telescope should be accomplished. The geotechnical data listed is essential not only for planning site leveling (preparation) and the design of the telescope foundation but also verifying designs of the construction equipment to be used at the telescope site. Figure 1 (Chua and Johnson, 1991) shows one proposed approach to large lunar telescope construction that illustrates some of the points of this paragraph. As part of the common lunar lander program, some simplified aspects of sensing and telepresence applicable to robotic construction of a large telescope can be investigated.

4. Contamination/interference control for a large lunar telescope will be essential. The one-meter class telescopes envisioned to become payloads for the common lunar lander should be instrumented to furnish data on their contamination



[1] Install footings
[2] Lay rails and temporary footings
[3] Fabricate and place tripod legs along rails
[4] Install azimuth drive assembly
[5] Install yoke, shaft and counterweights
[6] Install gimball ring and trunnion
[7] Assemble Trusses
[8] Place mirror assemblies
[9] Install secondary mirror
[10] Jack up LLT assembly

Figure 1. Proposed Construction Steps for the LLT

3,7,

and interference environments which will later be of value in designing contamination/interference control measures for the large lunar telescopes. Of interest are materials interactions and outgassing on the Moon, avoidance zones for other landings, dust (as previously mentioned), the communications and data relay noise, waste heat and radiation from power sources, stray light, and natural and machine-induced ground shock and vibrations (and regolith damping of these motions).

5. Stable precision structures technology will be a part of the small telescopes initially deployed on the Moon by the common lunar lander bus. Satisfactory performance of these structures will begin to provide the data base for larger and more complex telescopes to follow. Our suggestion is to design the small telescopes and their instrumentation so that the data returned will be relevant to the decisions that must be made on structures and materials for large telescopes.

6. Design of optical systems for performance in the lunar environment raises many questions which we can begin to answer with careful attention to detail in the design of the common lunar lander program and the one-meter class telescopes to be flown to the Moon as a part of that effort. One aspect to be considered is the performance of coatings for optics and thermal control. Also, a large telescope with a segmented mirror will require many actuators, a sensor and measurement system, and controls technology. Components of this scheme (in simplied form) could be tested on the Moon in the common lunar lander program.

7. Test and evaluation technologies for large lunar telescopes (e.g., a 16-meter segmented reflector and a LOUISA) will be an even greater challenge than they were for predecessor free-flyer telescopes in Earth orbit. We believe that the common lunar lander program offers a pathway to an early and systematic start on the testing program for simplified but relevant components of large lunar telescopes. To allow this path to be followed will require a break with some traditional ways of doing business. First it will be necessary to establish that there is a plan to eventually place a 16-meter class telescope and a LOUISA on the Moon. It will also be necessary to have some agreement as to how these telescopes would be designed so that significant new technologies to be used could be conceptualized and (in simplified form) tested and evaluated on the Moon as part of the Common Lunar Lander Program.

RECOMMENDATION

The early lunar observatories of the one-meter class, and later lunar-based telescopes of increasing complexity, call for imaginative solutions to diverse problems in optics, controls, structures, geotechnical engineering, construction, and environmental engineering. We feel that the best pathway for solving these problems is through a long-term plan in which each step builds on the past. The common lunar lander program, as we have pointed out, offers the opportunity to take the first step.

ACKNOWLEDGEMENTS
We acknowledge the support of the National Aeronautics and Space Administration, New Mexico State University, the University of New Mexico, and BDM International, Inc. in this effort. Discussions with Max Nein and Billie Davis of NASA Marshall Space Flight Center (particularly regarding the 16-meter and precursor telescopes) have influenced our thinking in these areas.

C-2

REFERENCES

Bahcall et al.(1991). "Astronomy from the Moon." Section 6 in The Decade of Discovery in Astronomy and Astrophysics, report by the Astronomy and Astrophysics Survey Committee, NRC, National Academy Press, Washington, D.C.

Bely, P. et al.(1989). "Foreword (with preliminary specifications and artist's rendition of 16 meter lunar-based telescope concept)." The Next Generation Space Telescope, P. Bely, C. Burrows, and G. Illingworth, editors, Space Telescope Science Institute, Baltimore, MD, pages 1-4.

Burke, B.F., (1990). "Astrophysics from the Moon." Science, Vol. 250, No. 4986, pages 1365-1370.

Burns, J.O., N. Duric, S.W. Johnson and G.J. Taylor (1990a). "LOUISA: A Lunar Optical-Ultraviolet- Infrared Synthesis Array."Engineering, Construction, and Operations in Space II, S.W. Johnson and J.P. Wetzel, editors, American Society of Civil Engineers, New York, NY, pages 677-686.

Burns, J.O., N. Duric, G.J. Taylor, and S.W. Johnson (1990b). "Observatories on the Moon." Scientific American, Vol. 262, No. 3, pages 42-49.

Carrier, W. David, III (1991). Lunar Geotechnical Institute letter regarding geotechnical issues to be addressed with lunar lander, Lakeland, FL.

Chua, K.M. and S.W. Johnson (1991). "Foundation, excavation, and radiation shielding emplacement concepts for a 16-meter lunar telescope."SPIE Proceedings, Vol. 1494, Paper 1494-17, SPIE, Bellingham, WA.

Criswell, D. (1972). "Lunar dust motion." Proceedings of Lunar Science Conference, 3rd NASA, Washington, D.C., pages 2671-2680.

Illingworth, G.D. (1990). "16 meter UV-Visible-IR lunar-based telescope." Astrophysics from the Moon, M.J. Mumma and H.J. Smith, editors, American Institute of Physics Conference Proceedings 207, New York, N.Y., pages 472-485.

Johnson, S.W., K.M. Chua, J.O. Burns, and F.A. Slane (1991). "Lunar dust: Implications for astronomical observatories." SPIE Proceedings, Vol. 1494, Paper 1494-23, SPIE, Bellingham, WA.

Johnson, S.W. and J.P. Wetzel (1989)." Required technologies for a 10-16 meter UV/Visible/IR telescope on the Moon." The Next Generation Space Telescope, P. Bely, C.J. Burrows and G.D. Illingworth, editors, Space Telescope Science Institute, Baltimore, MD, pages 348-359.

Nein, M.E., and B. Davis (1991). "System concepts for a large UV/optical/IR telescope on the Moon." SPIE Proceedings, Vol. 1494, Paper 1494-15, SPIE, Bellingham, WA.

ENGINEERING & TECHNOLOGY

A MICROWAVE SPACE POWER BEAMING FLIGHT EXPERIMENT

THE CENTER FOR SPACE POWER AT TEXAS A&M UNIVERSITY

ALAN M. BROWN
MICROWAVE PROJECT ENGINEER

INTRODUCTION

- THE CENTER FOR SPACE POWER AT TEXAS A&M UNIVERSITY IS ONE OF 16 CENTERS FOR THE COMMERICAL DEVELOPMENT OF SPACE (CCDS) SPONSORED BY THE NASA OFFICE OF COMMERCIAL PROGRAMS (CODE C).

- A MAJOR AREA OF INTEREST AND RESEARCH HAS BEEN IN POWER BEAMING, WHICH CAN BE DEFINED AS LOCALIZED OR CENTRAL POWER GENERATION WITH DISTRIBUTION TO REMOTE USERS VIA ENERGY BEAMS.

- MANY POSSIBLE APPLICATIONS:

  → EARTH TO SPACE
  → SPACE TO MOON
  → EARTH TO HIGH ALTITUDE
  → SPACE TO MARS
  → SPACE TO SPACE
  → SPACE TO EARTH
  → MOON TO EARTH

- SPACE APPLICATIONS RECEIVE THE BENEFITS OF A CENTRALIZED POWER SOURCE.

PAST POWER BEAMING ACTIVITIES

- RAYTHEON DEMONSTRATED A MICROWAVE POWERED HELICOPTER IN 1964. DURATION TESTS OF UP TO 10 HOURS WERE PERFORMED.
- DR. PETER GLASER OF A. D. LITTLE, INC., PROPOSED THE SOLAR POWER SATELLITE CONCEPT IN 1968. INTENSIVE STUDY EFFORTS WERE TO FOLLOW FOR THE NEXT TEN YEARS.
- GOLDSTONE EXPERIMENT TRANSMITTED POWER OVER A DISTANCE OF 1.54 KM, WITH AN OUTPUT OF 34KW DC IN 1975.
- THE INSTITUTE OF SPACE AND ASTRONAUTICAL SCIENCE (ISAS) OF JAPAN FLEW A ROCKET EXPERIMENT CALLED MINIX THAT STUDIED THE INTERACTION BETWEEN THE SPACE ENVIRONMENT AND A MICROWAVE POWER BEAM.
- COMMUNICATION RESEARCH CENTRE OF CANADA FLEW A PROTOTYPE OF A MICROWAVE POWERED AIRPLANE. IN 1987. A FULL SCALE VERSION, CALLED SHARP (STATIONARY HIGH ALTITUDE RELAY PLATFORM) IS ENVISIONED TO PROVIDE MANY DIFFERENT COMMERICAL SERVICES.

FUTURE ACTIVITIES

- FOREIGN ACTIVITIES

  JAPANESE HAVE ANOTHER ROCKET EXPERIMENT PLANNED FOR 1992.
  EUROPEAN COMMUNITY
  USSR
  CANADIANS

- THE SYNTHESIS GROUP REPORT, "AMERICA AT THE THRESHOLD", IDENTIFIED POWER BEAMING IN SEVERAL AREAS:

  IN ARCHITECTURE IV, POWER BEAMING EXPERIMENTS ARE PLANNED FOR AS PART OF THE LUNAR NOC -1(NEXT OPERATIONAL CAPABILITY).

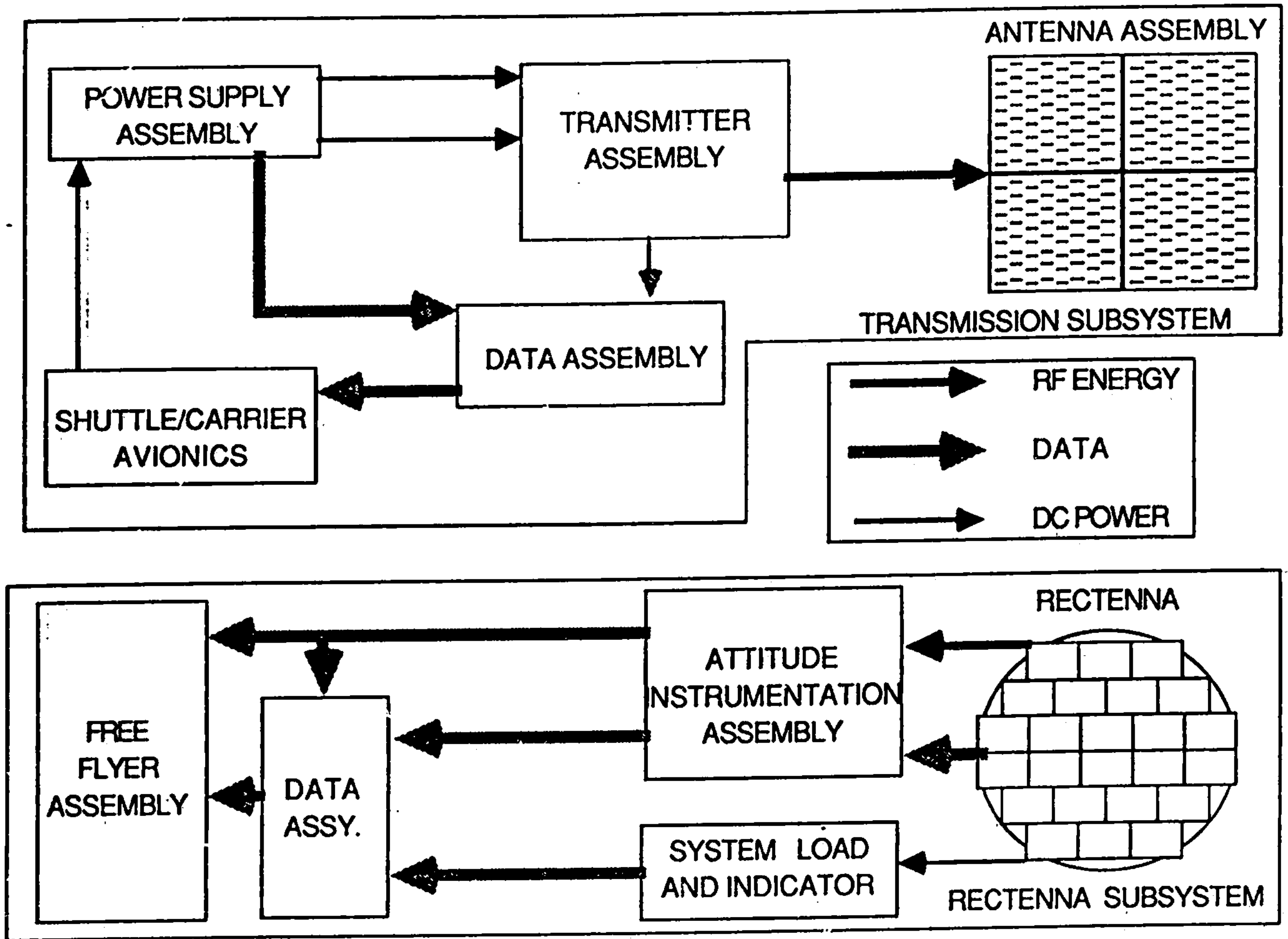
  IDENTIFIED AS A DEVELOPMENT PROGRAM IN THE POWER AREA OF SUPPORTING TECHNOLOGIES.

  THE ENERGY TO EARTH WAYPOINT DEFINES POWER BEAMING AS 1 OF 2 LUNAR ACTIVITIES TO PROVIDE ENERGY TO EARTH, AND STATES THAT EARTH AND LUNAR-BASED EXPERIMENTS ARE REQUIRED.

EXPERIMENT OBJECTIVES

- DEMONSTRATE THE CONCEPT OF MICROWAVE POWER BEAMING IN THE SPACE ENVIRONMENT.
- VERIFY SYSTEMS ANALYSIS MODELS DEVELOPED TO PREDICT SYSTEM PERFORMANCE IN THE SPACE ENVIRONMENT.
- PROVIDE THE TECHNOLOGY LEGACIES NEEDED FOR THE FUTURE APPLICATIONS.
- CREATE A NATIONAL TEAM COMPRISED OF INDUSTRY, GOVERNMENT, AND ACADEMIA PERSONNEL WITH THE EXPERTISE TO SUCCESSFULLY DEPLOY AND COMMERCIALIZE THIS TECHNOLOGY.

SYSTEM BLOCK DIAGRAM



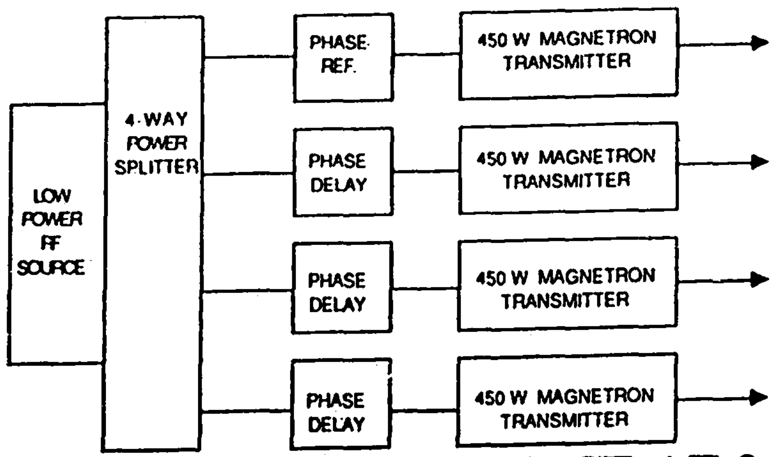
SEQUENCE OF EVENTS

- **PART 1**
  - RMS ATTACHES TO GRAPPLE FIXTURE ON SPARTAN
  - RMS ALIGNS RECTENNA WITH TRANSMISSION ANTENNA, 15 METER SEPARATION
  - ALIGNMENT IS VERIFIED PRIOR TO POWER UP
- **PART 2**
  - POWER APPLIED TO ALL FOUR MAGNETRONS.
  - RECTENNA WILL CONVERT THE RF ENERGY INTO DC, AND DRIVE A LOAD, WHICH CAN BE VISUALLY MONITORED FROM THE SHUTTLE. DC POWER DATA WILL BE RECORDED.
- **PART 3**
  - THE FOUR MAGNETRONS ARE POWERED DOWN.
  - RMS WILL RELEASE THE SPARTAN AND THE SPARTAN WILL MAINTAIN ATTITUDE TOWARDS THE SHUTTLE AND THE TRANSMISSION ANTENNA.
  - POWER IS APPLIED TO ALL FOUR MAGNETRONS AGAIN.
  - DC POWER DATA WILL BE RECORDED UP TO SEPARATION DISTANCE OF 200 METERS.
- **PART 4**
  - SHUTTLE/RMS WILL RETRIEVE SPARTAN AFTER USEFUL DATA RECORDING HAS BEEN COMPLETED.

CENTER FOR SPACE POWER
TEXAS A&M UNIVERSITY

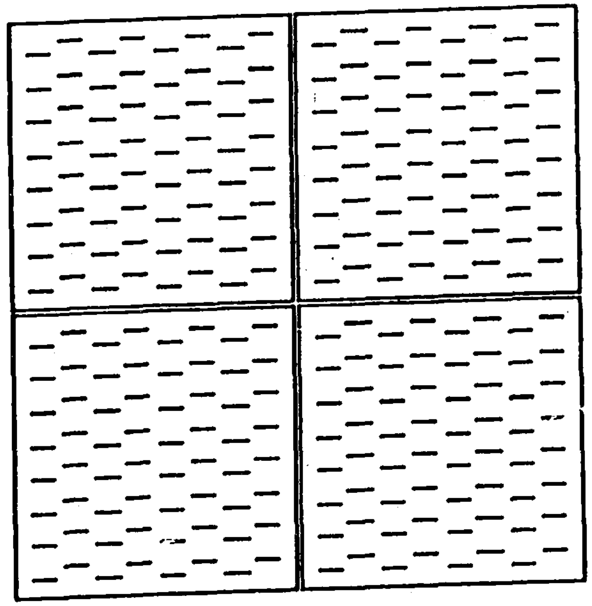
A NASA CENTER FOR THE COMMERCIAL DEVELOPMENT OF SPACE

TRANSMITTER ASSEMBLY



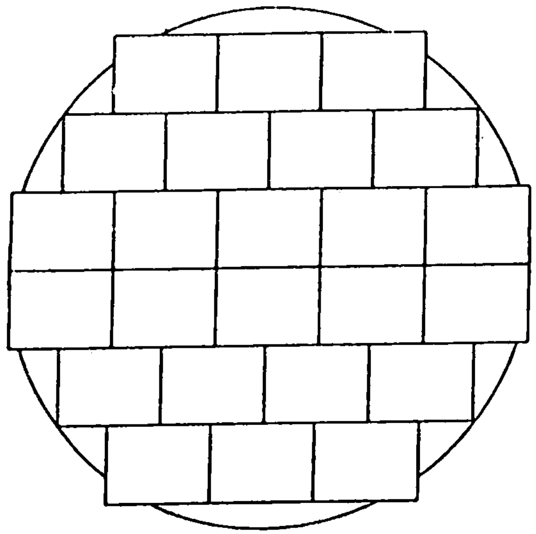
- REDUNDANT LOW POWER RF SOURCE AT 2.45 GHZ
  - ALLOWS FOR GRACEFUL DEGRADATION
- HIGH GAIN MAGNETRON AMPLIFIER
  - 450 W RF OUTPUT POWER (DESIGN GOAL)
  - RADIATION COOLED, SPACE QUALIFIED
- MODULAR PHASE DELAY CIRCUITRY
  - UPGRADE FOR ELECTRONIC BEAM STEERING MORE EASILY IMPLEMENTED

ANTENNA ASSEMBLY



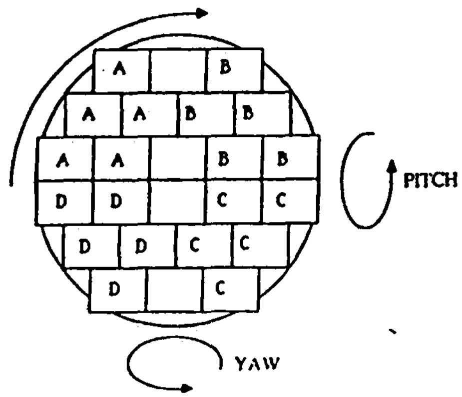
- PHASED ARRAY USING SLOTTED WAVEGUIDES
  - 4 PANELS ARRANGED IN A SQUARE
  - EACH PANEL IS 30" X 30" WITH 64 RADIATING ELEMENTS

RECTENNA ASSEMBLY



- 24 PANELS IN A CIRCULAR ARRANGEMENT
  - EACH PANEL IS 18" X 24", RESULTS IN APPROXIMATELY 10' DIAMETER CIRCLE.
  - PANELS ARE OPTIMIZED FOR LOW POWER DENSITY INCIDENT BEAMS
  - EACH PANEL WILL CONTAIN SIX (6) STRINGS WITH 8 DIPOLES PER STRING. EACH STRING HAS TWO DIODES AND ASSOCIATED FILTERS.

ATTITUDE INSTRUMENTATION ASSEMBLY



- QUADRATURE SENSING
  - PROVIDES INDICATION OF POSITION OF RECTENNA IN THE BEAM
  - MAY BE USED AS FEEDBACK FOR FUTURE BEAM STEERING

- RF ATTITUDE INSTRUMENTATION
  - USES PHASE AND MAGNITUDE MEASUREMENTS TO PROVIDE RELATIVE POSITION ABOUT ROLL, PITCH, AND YAW AXES
  - WILL PROVIDE ERROR SIGNAL TO FREE-FLYER ACS TO ENSURE THE TWO APERATURES REMAIN PARALLEL

POSSIBLE INTEGRATION WITH THE COMMON LUNAR LANDER

- SINGLE LUNAR LANDER APPLICATION

  INSTALL A DEPLOYABLE RECTENNA THAT COULD BE USED FOR FUTURE EXPERIMENTS, IN WHICH ANOTHER LUNAR BOUND ASSET COULD PROVIDE THE TRANSMISSION SUBSYSTEM.

- DUAL LUNAR LANDER APPLICATIONS

  INSTALL A DEPLOYABLE RECTENNA, AND THEN BEAM FROM A SUBSEQUENT CLL DURING THE 14 DAY ORBIT PHASE.

  INSTALL A DEPLOYABLE RECTENNA, AND THEN BEAM FROM A SUBSEQUENT CLL AFTER LANDING.

- MULTIPLE LUNAR LANDER APPLICATIONS

  BEAM FROM A SURFACE TRANSMITTER TO A SURFACE RECTENNA BY REFLECTING OFF AN RF MIRROR ON A CLL DURING THE 14 DAY ORBIT PHASE.

Autonomous Approach & Landing System Study / Test Program

1 July 1991

R. E. Jones
619-547-4581

GENERAL DYNAMICS
Space Systems Division

INTRODUCTION

- JOINT AA&L - AR&D SYSTEM TEST PROGRAM PROPOSED FOR 1992
  - system test on GD simulator then at JSC and MSFC
  - simulator performance measurement capability verified
- PARTICIPANTS: GD, JSC, MSFC, LaRC, ARC
- AA&L flight test proposed in 1993
- APPLICATIONS: Common Lunar Lander, Personnel Launch System
  High Speed Civil Transport, Advanced Manned Launch
  System, Single Stage to Orbit, SEI Vehicles

SYSTEM DESCRIPTION

FEATURES:

- Cruise Missile derived Image Processing System (IPS) accomodates a variety of sensors.
- Integrated GPS / IPS / INS provides a robust, scaleable and easily reconfigured architecture
- Mature system elements minimizes integration and development costs

ISSUES:

- Safety & Operational Efficiency
  - AR&D system upgradeable form single to dual fault tolerant.
  - Autonomous docking capability provides collision avoidance in all operational modes.
  - Uses established Astronaut visual and control interfaces.
  - Simplifies training and reduces recurring costs.
  - Image Processor handles autodock & autoland functions when required.
- COST EFFECTIVENESS
  - Integrating 2 mature systems minimizes developmental costs
  - Systems architecture is open and scaleable. Will use Common Modules.
  - Easily reconfigured via S/W and H/W

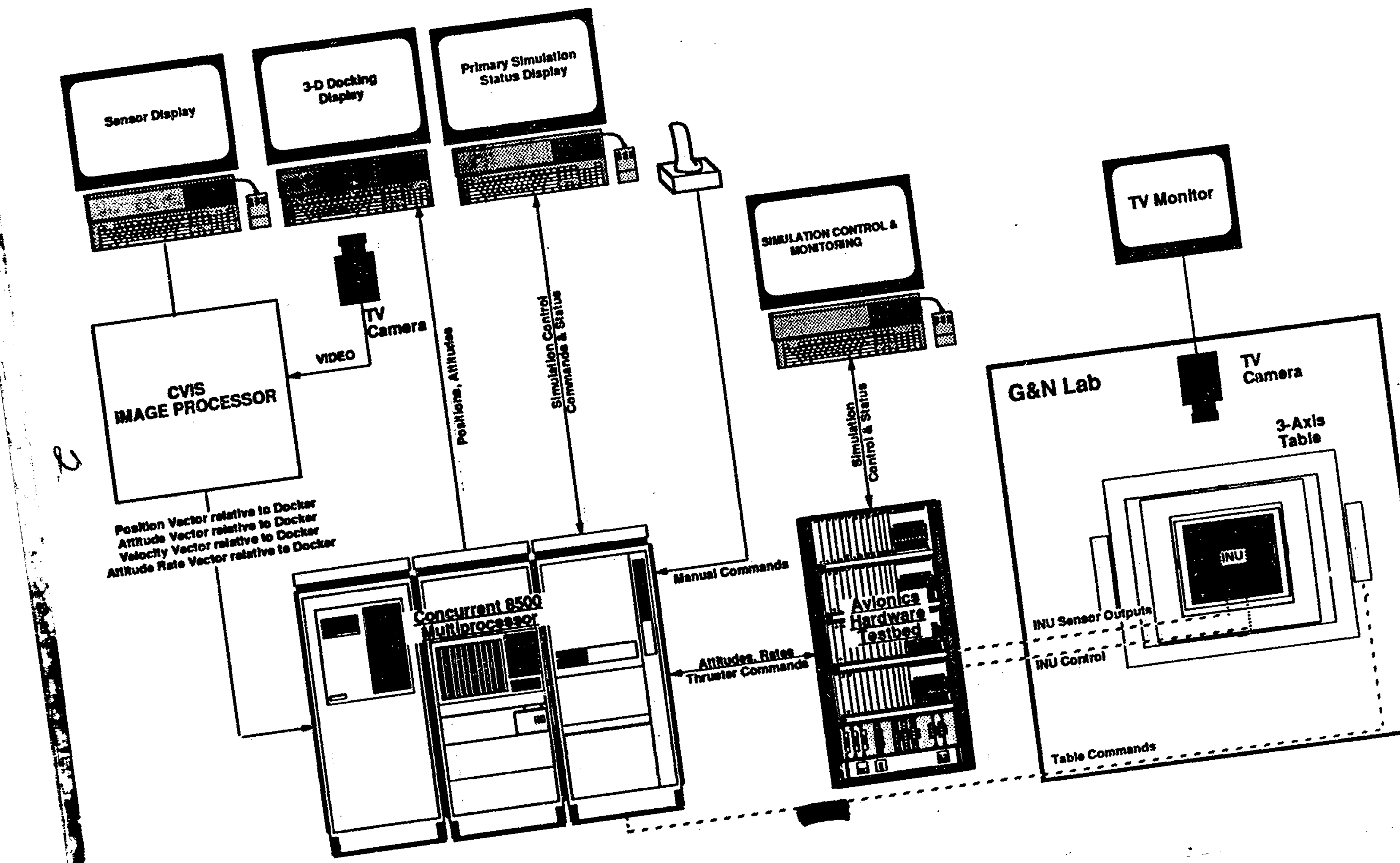
REJ 6 June 91

Basic Simulator Design Features:

- Real Time, Hardware in the Loop Simulation
- Rapidly Reconfigureable
  - Reference Missions / Phases
  - Supports element or system testing
  - Switchable Modules provide flexibility
  - Interconnected with Resource Labs
- Evaluates System Performance
  - GN&C System performance / reliability
  - Docking Mechanism Design / Contact Parameters
  - Docking System Design - sensor types, target acquisition
  - Sensor Operational Limitations - Sun angles, range, FOV
  - Target design, placement

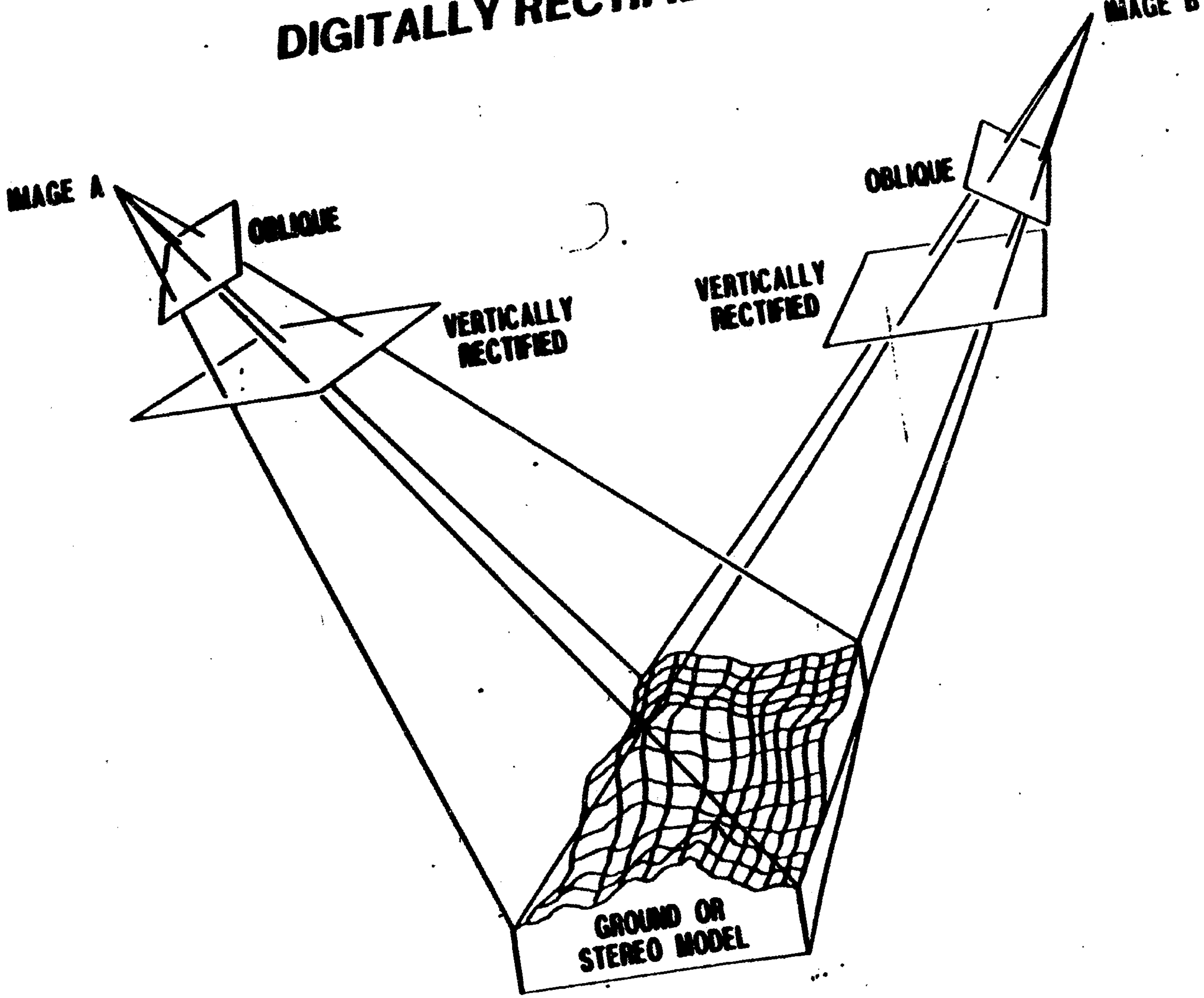
AUTONOMOUS APPROACH & LANDING SYSTEM

Simulator Configuration

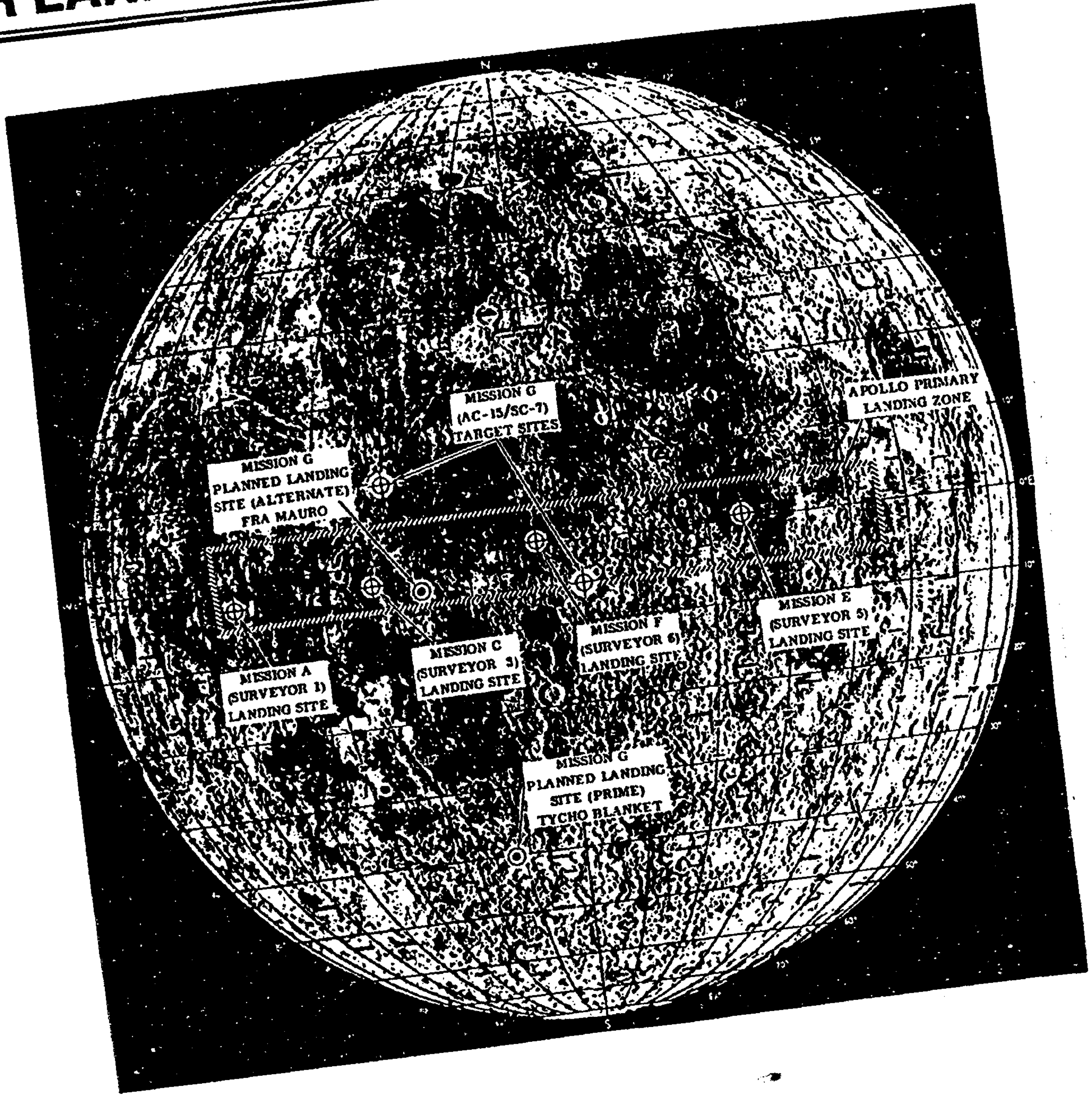


2

DIGITALLY RECTIFIED STEREO



SURVEYOR LANDING SITES



ACTION PLAN

- **FY-91**

  - Jointly define AA&L operational and system requirements
  - Develop & demonstrate the AA&L system Image Processing subsystem using the upgraded AR&D simulator.
  - Conduct a cooperative study using the simulator to explore navigation / Autoland system operations for 2 target applications.

- **FY-92 - 9X**

  - Test and quantify AA&L system / element performance at 2 or more NASA test facilities.
  - Verify ARD&L simulator performance measurement capabilities.
  - Help develop, integrate and flight test a GPS / IPS based AA&L system contrasting the performance of several candidate sensors and operational modes

Workshop on the Concept of a Common Lunar Lander

Engineering & Technology Session

Bret Drake
Lunar & Mars Exploration Program Office
July 1, 1991

Synthesis Group Waypoints
Emphasis on small lunar precursors

Lunar Exploration :
- ❑ Emplacement of a geophysical global network (8)
- ❑ Surface rover for "pre-reconnaissance

Habitation :
- ❑ Lunar operations at the bench scale and concept levels
  - Regolith and substrate characterization
  - Movement of loose regolith
  - Testing of prototype construction equipment

Lunar Based Observation :
- ❑ Surface/subsurface survey via a robotic rover
- ❑ Environmental survey instruments (100 kg)
- ❑ Magnetospheric Observatory (10 kg)
- ❑ Operations Test Telescope (300 kg)

NASA

Synthesis Group Waypoints
Emphasis on small lunar precursors

Fuels :

- ❑ Site survey and certification via a robotic rover
  - Chemical, mineralogical, and physical soil property measurements
  - Volatile quantification
- ❑ Automated resource production demonstrations

Energy to Earth :

- ❑ Prototype resource extraction systems are emplaced on the Moon to demonstrate feasibility and gain operational experience
  - Volatile extraction (O_2, H_2, CO, CO_2, CH_4, N_2)
  - Operational prototyping
  - Highly automated
  - 2-4 t

The Role of a Small Lunar Cargo Lander In the Space Exploration Initiative

Technology Demonstrations

- ❑ Hazard avoidance
- ❑ Precision landing
- ❑ In Situ Resource Utilization
- ❑ Science packages/systems
- ❑ Autonomous operations
- ❑ Dust maintenance

The Role of a Small Lunar Cargo Lander In the Space Exploration Initiative (Continued)

Landing Site Characterization

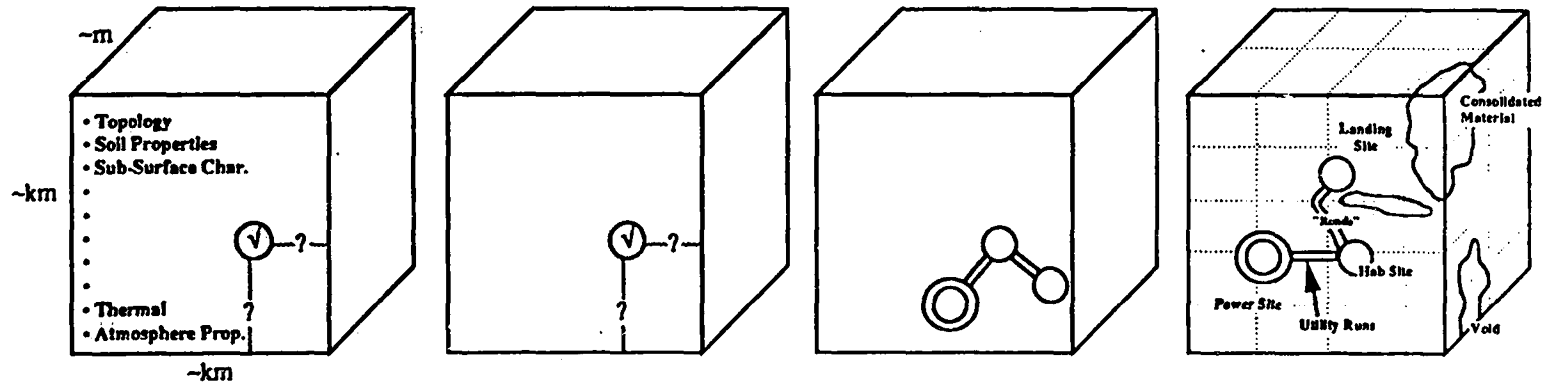
❑ Surface data
- Soil physical properties
- Craters
- Rock/rubble distribution
- Subsurface structure
- Thermal properties
- Temperature variations
- Composition
- Soil chemistry
- Topography
- Electromagnetic properties
- Seismic activity

❑ Radiation & Particles
- Solar flux
- Galactic cosmic ray flux
- Meteoroid flux

❑ Magnetic & Gravity Fields
- Local magnetic fields
- Gravity field

PRECURSOR PHILOSOPHY

	LO	SRO	ROV / RSR	OCR	
	L- (8-10 years)	L- (4-6 years)	L- (2-4 years)	L- (1-2 years)	Launch (L)
DEVELOPMENT ACTIVITY	Concepts; Prelim Design	Final Design; Construction	Test, Evaluation and Certification	Ops Planning	Ops Support
DATA NEED	• Mobility Concepts • Construction Techniques • ISRU Concepts • Initial Ops Concepts	• Design Analysis • Sub-system Trades and Selection • ISRU Process Selection • Ops/Engineering Synergy	• Test Plans & Facilities • Certification Process • Performance to Spec - Off Nominal Perf.	• Systems Certification • Surveys/Platting • Architectural Layouts • Final Manifesting • Ops Procedures	
	"Classes" of Sites	n Specific "Named" Sites	Selected Site	Selected Site	• Ops Support - Rover Route Planning - Growth Plans - Alternate Sites
DATA CHARACTERISTICS	• Resolution ~<M • Uncertainty ~ROM ~ x 2 • Within "regions" of typical geography	• Resolution ~<M • Uncertainty ~1/2 ROM ~ x 20% • Within n potential sites	• Resolution ~<M • Uncertainty ~ x 2 ~ x 10% • Within selected site	• Resolution ~<M • Uncertainty ~% • 3-Dimensional survey of selected site	
EXAMPLE	• Apollo • Survey • Ranger • Luna • Viking • MR/(SR?)	• LO, MO, Penetrators • Landers • Mariner, Viking Orbiter • MR/SR (?)	• Hi-Res LO/MO • Landers • MR/SR	• "Project" robotic mission - Science content ~(?)	• Hi-Res LO/MO - Support Ops • Robotic Rovers



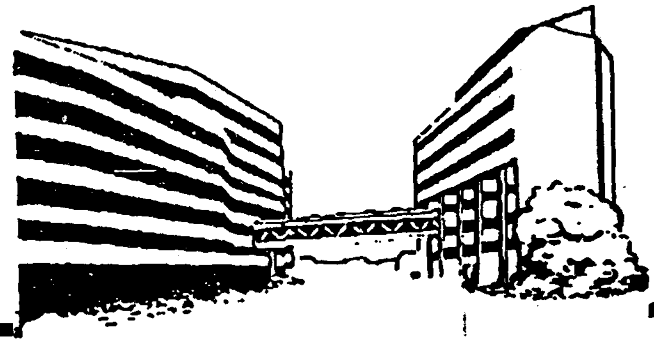
BPAR/Barrios/BRoberts/Precursor Phil/GJP-7/5/90

6.

Common Lunar Lander GN&C
and
SEI GN&C Technology

Ken Spratlin
(617)258-2441
July 1, 1991

THE
CHARLES STARK DRAPER
LABORATORY, INC.



Related CSDL Activities

- Apollo GN&C Prime Contractor
- Lunar/Mars Initiative Corporate Sponsored Research
  - Navigation Infrastructure Requirements and Performance
  - Autonomous Landing GN&C
- Image Recognition Systems Corporate Sponsored Research
  - Hazard Detection and Avoidance
  - Terrain Correlation (for navigation)
- NASA/JSC ER Task
  - Autonomous Lander Hazard Detection and Avoidance

DRAPER LABORATORY

Definitions

<u>Precision Landing (PL)</u>

landing within a few tens of meters of a designated map location

<u>Neighborhood Landing (NL)</u>

landing in the general vicinity (a few hundreds or thousands of meters) of a designated map location

<u>Hazard Detection and Avoidance (HDA)</u>

real-time detection and avoidance of hazards during landing

<u>Site Certification</u>

a priori detection of hazards so as to ---

(1) certify no hazards or acceptable risk within footprint, or

(2) certify existence of acceptable landing sites for HDA

DRAPER LABORATORY

Apollo Navigation

- Earth-based tracking (STDN) of CSM/LM prior to separation and deorbit of LM
  - CSM took landmark sightings that were downlinked to the ground processors to assist in tying vehicle inertial state to the lunar landmarks
- Uplink of state vector to CSM/LM prior to separation and deorbit of LM
- CSM/LM and then LM perform inertial navigation until LM landing
  - LM performed deorbit burn on the back side of the moon out of Earth-based tracking
  - Additional Earth-based tracking was performed once LM came out of LOS and a landing site location offset was uplinked to account for any new navigation errors

DRAPER LABORATORY

Navigation Error Sources

- Moon gravity models caused large errors in orbit propagation
- The Lunar maps were accurate for relative locations of surface features but not for the location of features with respect to inertial space
  - Inertial errors on the order of several kilometers were typical

4

DRAPER LABORATORY

Apollo Performance

- Without tracking between deorbit and landing, the 1σ navigation accuracy near landing was approximately

Source	Crosstrack	Downrange	
IMU	1150	8200	
STDN	3200	6400	
Combined	3400	10400	feet

- Current generation IMU's are significantly better than Apollo IMU so should be able to reduce IMU component to approximately 300 feet CT and 1500 feet DR
- Apollo 12 used tracking between deorbit and landing, and would have landed within 170 feet of Surveyor had the crew not diverted to avoid landing in a crater

DRAPER LABORATORY

SEI GN&C Technology Demos

- Hazard Detection and Avoidance
  - Sensors - collect performance data in real environment
    - Intensity
    - Laser ranger
  - Collect real terrain data for use in sensor/algorithm development and evaluation
- Precision Landing
  - Test navsite (beacon) operation and use by lander
  - Collect data for terrain correlation sensor/algorithm development and evaluation

DRAPER LABORATORY

AUTONOMOUS LANDING FLIGHT EXPERIMENTS

COMMON LUNAR LANDER WORKSHOP

HOUSTON, TX
JULY 1 - 2, 1991

Ken Baker
ER2/Intelligent Systems Branch
Automation & Robotics Division
Engineering Directorate
NASA Johnson Space Center
Phone: (713) 483-2041
NASAMAIL - kenbaker

PURPOSE OF PRESENTATION

Briefly Describe Two Autonomous Landing[1] Flight Experiments for the Common Lunar Lander

OUTLINE

- Objectives
- Background
  - — Autonomous Landing for Mars Exploration
  - — Basic Technical Approach
- Hybrid Image Matching Navigation for Precision Landing Experiment
- Imaging Laser Radar On-Board Hazard Detection Experiment

[1] This Is an Application of an On-Going NASA (Code R/Exploration Technology) Project.

FLIGHT EXPERIMENT OBJECTIVES

A Lunar Landing Test of the Approaches Being Considered in the Exploration Technology Development Program for a Mars Landing Would:

- Provide Quantitative Performance for One or More Sets of Landing Conditions
- Be More Realistic Than A Field Test Done Using Earth Analogs of Mars Terrain
- Demonstrate End-to-End System Performance of a Space Qualified System
- Require Integration of the On-Board & a Priori Information Elements of the Landing Problem

OBJECTIVES of LANDING TECHNOLOGY DEVELOPMENT for MARS EXPLORATION

Develop Technology to Enable Landing of Planetary Exploration Spacecraft:

- *Safely* in the Face of Surface Hazards Presented by Rough Terrain
- *Accurately*, i.e. Close to the Area of Mission Interest
- *Autonomously*, i.e. Without Real-Time Ground Control

BENEFITS

- Increased Probability of Safe Landing
- Reduced Structural Mass Needed to Make the Lander *Robust* Enough to Survive Touchdown
- Reduced Resources Needed to Survey Area of Mission Interest from *Orbit* Until *Safe* Landing Site Is Found

BASIC TECHNICAL APPROACHES to a MARS LANDING

Precision Landing

- *Scenario:*
  - — Select, Prior to Deorbit, a Safe Landing Site Using High Resolution Orbital Imagery
  - — During Descent, Maneuver Accurately Enough to Land Within That Site
- *Prior Information:* Imagery/Terrain Elevation Maps Necessary to Select: Safe Landing Sites & "Landmarks" for Navigation
- *Technology:* Sensor, Algorithm & On-Board Computer to Provide Navigation Measurements With Respect to the Surface of the Planet That Are:
  - — Accurate
  - — Robust to Variations in Observation & Illumination Geometry, etc.

On-Board Hazard Detection & Avoidance

- *Scenario:*
  - — Aim Lander At Area *Expected* A Priori to Contain Safe Landing Sites Within Its Maneuver Range
  - — In Real-Time Detect a Safe Site & Maneuver to Land There
- *Prior Information:* Imagery/Terrain Elevation Maps & Geological Knowledge to Select Such Areas
- *Technology:* Sensor, Algorithm & On-Board Computer for Reliable Detection of Landing Hazards During Terminal Phase of Descent

HYBRID OPTICAL IMAGE MATCHING NAVIGATION

Instrument: A Terrain Relative Image Matching Navigation Sensor That Uses:

- Images in the Visible
- Terrain Elevation Maps
- A Synthetic Estimation Filter for Detecting Selected Terrain Patches That Is Robust to Deviations from the Nominal Vehicle Trajectory
  — This Scheme Is Being Tested In FY91 Using Images of Simulated Mars Terrain
- A Flight Qualified Optical Image Correlator Under Development by DARPA

Experiment: Test This Navigation Sensor Using a Safe Landing Site and Landmarks Chosen on the Basis of a Priori Imagery & Terrain Elevation Maps

LANDER DESIGN

RADIOISOTOPE POWER SYSTEMS

FOR THE

COMMON LUNAR LANDER PROGRAM

BY
EDWARD F. MASTAL
U.S. DEPARTMENT OF ENERGY
WASHINGTON, D.C.

COMMON LUNAR LANDER WORKSHOP
JOHNSON SPACE CENTER
HOUSTON, TX
JULY 1-2, 1991

INTRODUCTION

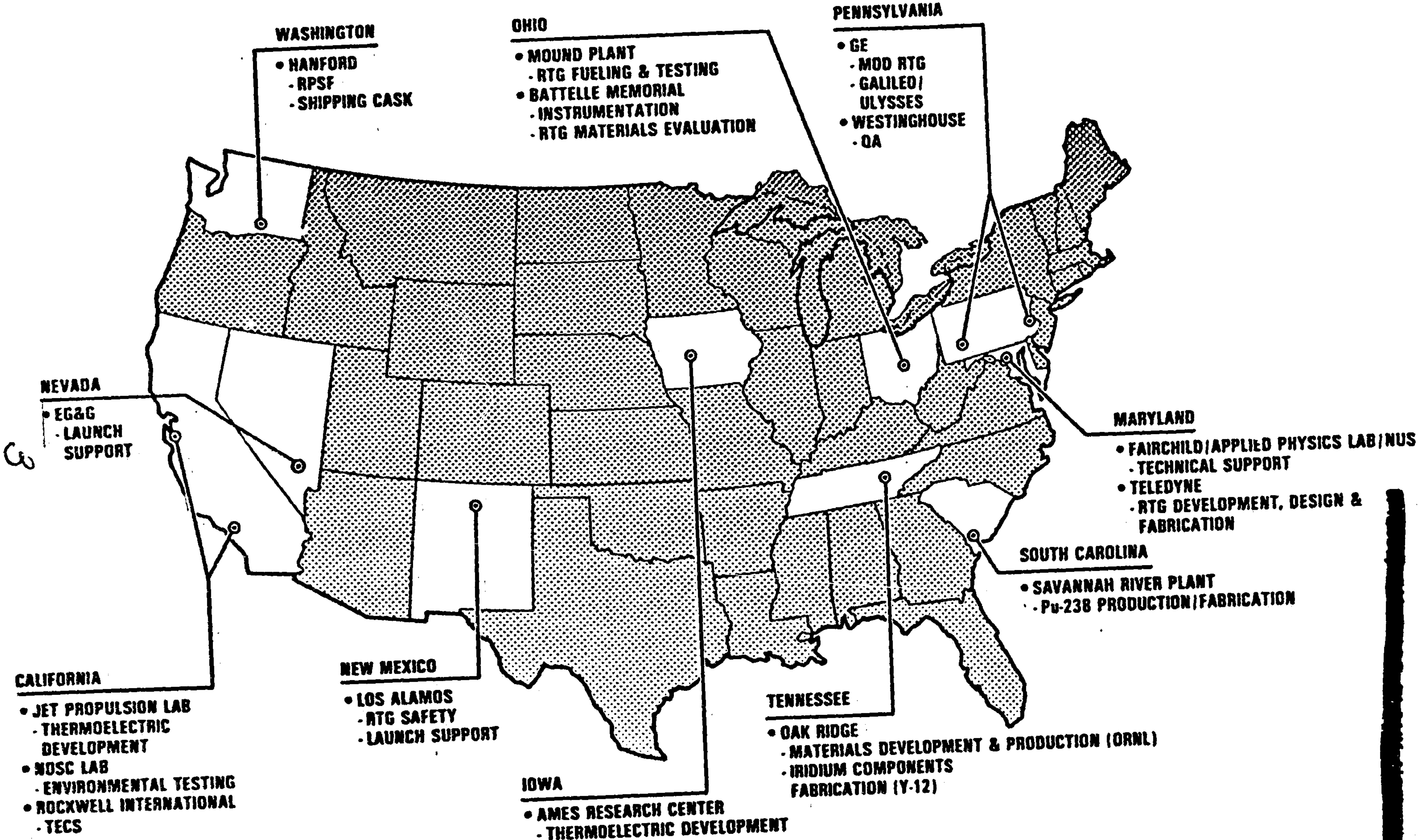
PURPOSE: To present an overview of Radioisotope Space Power Systems Technology Applicable to the Common Lunar Lander (CLL) program and to explain the steps necessary to provide such systems for NASA's CLL missions.

SCOPE OF DOE PROGRAM: The U.S. Department of Energy, Office of Special Applications is chartered to develop the technology; to design, fabricate, test, and deliver flight hardware; to maintain fuel/heat source production capability; and to assure the safe handling and use of Radioisotope Power Systems and thermal sources for NASA, DOD, and other space missions.

PARTICIPANTS: The Radioisotope Power Program activities are performed by a complex of industrial contractors, National Laboratories, and DOE field offices which are located throughout the United States. The Office of Special Applications manages and directs the program in close coordination with user agencies and other DOE programs. (I am the Deputy Director of that Office.)

ADVANCED NUCLEAR SYSTEMS

PRIMARY PARTICIPANTS



GENSA 02 107

BACKGROUND

- On 29 June 1991 we passed the 30th Anniversary of the first launch of a radioisotope power system into space.
- Over these 3 decades the U.S. has launched 41 Radioisotope Thermoelectric Generators (RTGs) on 23 spacecraft.
- On all types of launch vehicles from the Scout to the Shuttle.
- For missions in low and high earth orbit, to the Moon, to Mars, and past the outer planets - and beyond.
- Power levels of the RTGs cover the range of 2.7 to 288 Watts
- All were fueled with Plutonium-238 (87.7 year half-life).
- There have been 3 launch aborts involving RTGs - all met their design safety requirements.
- All flight RTGs have exceeded design power requirements - some are still operating after 19 years in space.

U.S. Has Successfully Flown 20 Isotopic Power Systems Since 1961

Power Source	Spacecraft	Mission Type	Launch Date	Status
SNAP-3A	Transit 4A	Navigational	06/29/61	Successfully achieved orbit
SNAP-3A	Transit 4B	Navigational	11/15/61	Successfully achieved orbit
SNAP-9A	Transit-5BN-1	Navigational	09/28/63	Successfully achieved orbit
SNAP-9A	Transit-5BN-2	Navigational	12/05/63	Successfully achieved orbit
SNAP-9A	Transit-5BN-3	Navigational	04/21/64	Mission aborted; burned up on reentry
SNAP-19B2	Nimbus-B-1	Meteorological	05/18/68	Mission aborted; heat source retrieved
SNAP-19B3	Nimbus III	Meteorological	04/14/69	Successfully achieved orbit
SNAP-27	Apollo 12	Lunar	11/14/69	Successfully placed on lunar surface
SNAP-27	Apollo 13	Lunar	04/11/70	Mission aborted on way to moon. Heat source returned to South Pacific Ocean.
SNAP-27	Apollo 14	Lunar	01/31/71	Successfully placed on lunar surface
SNAP-27	Apollo 15	Lunar	07/26/71	Successfully placed on lunar surface
SNAP-19	Pioneer 10	Planetary	03/02/72	Successfully operated to Jupiter and beyond
SNAP-27	Apollo 16	Lunar	04/16/72	Successfully placed on lunar surface
Transit-RTG	"Transit" (Triad-01-1X)	Navigational	09/02/72	Successfully achieved orbit
SNAP-27	Apollo 17	Lunar	12/07/72	Successfully placed on lunar surface
SNAP-19	Pioneer 11	Planetary	04/05/73	Successfully operated to Jupiter and Saturn and beyond
SNAP-19	Viking 1	Mars	08/20/75	Successfully landed on Mars
SNAP-19	Viking 2	Mars	09/09/75	Successfully landed on Mars
MHW	Les 8/9	Communications	03/14/76	Successfully achieved orbit
MHW	Voyager 2	Planetary	08/20/77	Successfully operated to Jupiter and beyond
MHW	Voyager 1	Planetary	09/05/77	Successfully operated to Jupiter and beyond
GPHS	Galileo	Planetary	10/18/89	Successfully launched and enroute to investigate Jupiter and its satellites in 1995
GPHS	Ulysses	Planetary/Solar	10/06/90	Successfully launched and enroute to investigate solar polar regions

5

CENSA 01 [redacted]

PREVIOUS LUNAR MISSION EXPERIENCE

- DOE (when it was AEC) developed and provided RTGs to NASA/JSC for use on the surface of the Moon.

- Five SNAP-27 powered Apollo Lunar Surface Experiment Packages (ALSEP's) were left on the Moon by U.S. astronauts during the Apollo 12, 14, 15, 16, and 17 missions.

- The ALSEP science packages were added after the Lunar Excursion Module (LEM) was designed; so it was decided to carry the heat source to the Moon in an external reentry cask. The astronauts then fueled the generators after landing.

- With proper integration during design of the spacecraft, the RTG can be launched fueled for unmanned missions.

- All five SNAP-27 powered ALSEP stations operated successfully until they were shutdown on September 30, 1977 to clear their radio frequencies.

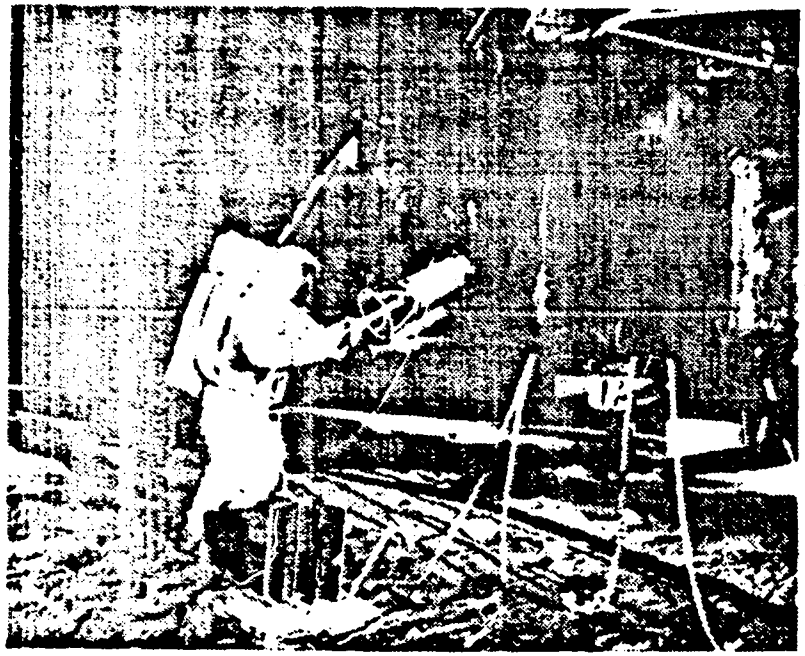
- Looking back at the Apollo launch schedule, it is unlikely that more than one or two stations would have been operating at any one time if solar cell power supplies had been used. At least three stations were required for lunar seismic experiments to locate the source of the activity. We ended up with five because of the long-lived RTGs.

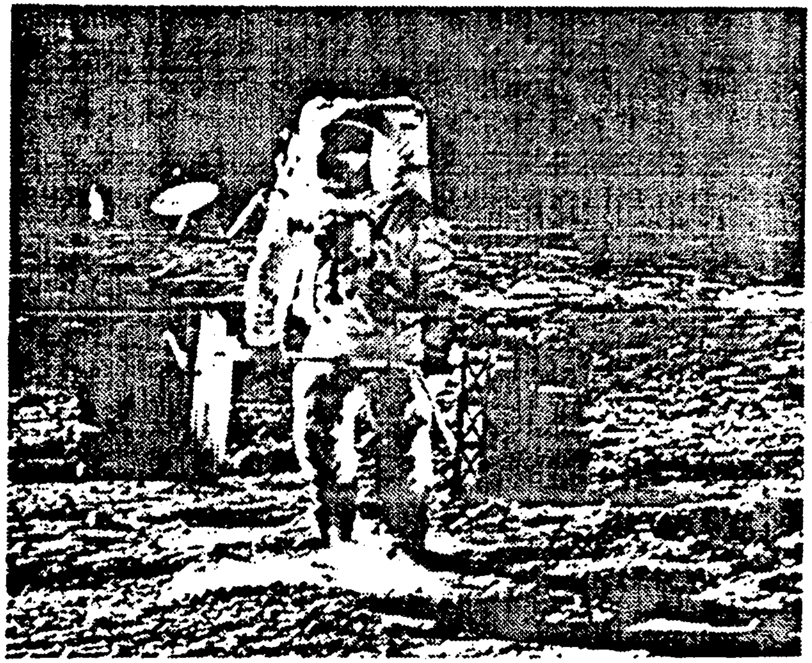
PREVIOUS LUNAR MISSION EXPERIENCE (Cont'd)

- The AEC also provided a Radioisotope Heater Unit (RHU) for use on the solar cell powered science package deployed by the Apollo 11 astronauts.
- A 25-watt SNAP-11 RTG was also developed by the AEC for use on the unmanned Surveyor soft lunar landing missions in the 1960's. However, it was never used on the NASA/JPL missions.
- There was a SNAP-27 unit on the Apollo 13 mission which flew around the moon in 1970 after the service module fuel cells blew up. Power from the LEM was needed for life support, so the LEM was not jettisoned until it returned to earth. The fuel cask survived reentry and fell into the deepest part of the Pacific ocean.

ALSEP/SNAP-27 DEPLOYMENT

APOLLO 12 - NOVEMBER 1969



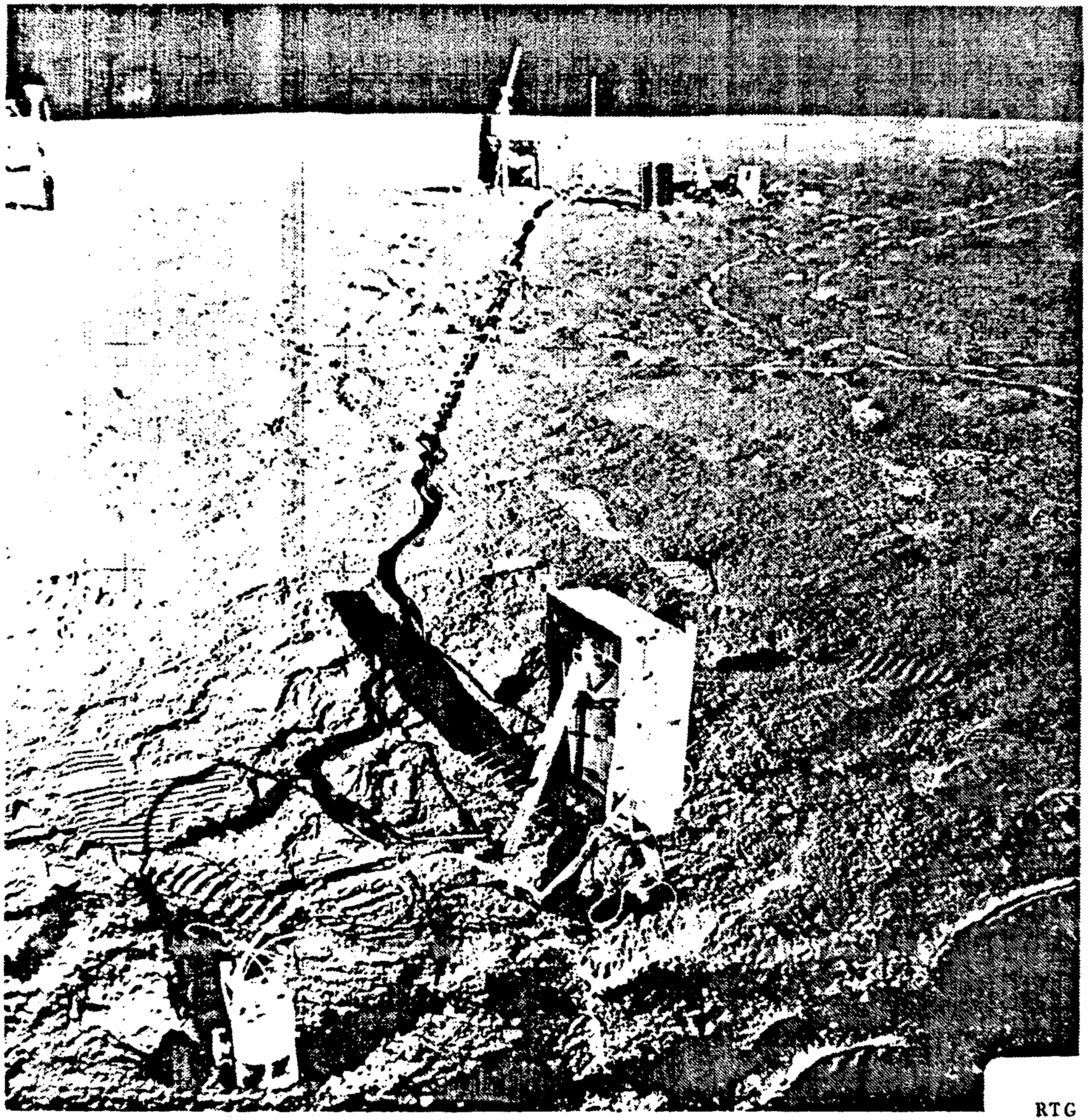


8

SNAP-27
SYSTEM CHARACTERISTICS

INITIAL POWER	73 Watts
LIFETIME	1 Year
FUEL	Pu 238
WEIGHT	
FUELED GENERATOR	43.5 lbs.
FUEL CASK	25.2 lbs.

RTG 05 111



RTG 05 117

RELATED MARS LANDER EXPERIENCE

- DOE (then AEC) developed and provided RTGs to NASA/Langley for use on the Mars Viking Lander missions in the 1970's.

- Two 35 We SNAP-19 RTGs provided total electrical power for each Viking Lander. Waste heat from the RTGs was used to control the temperature of the electronics during the cold Martian nights.

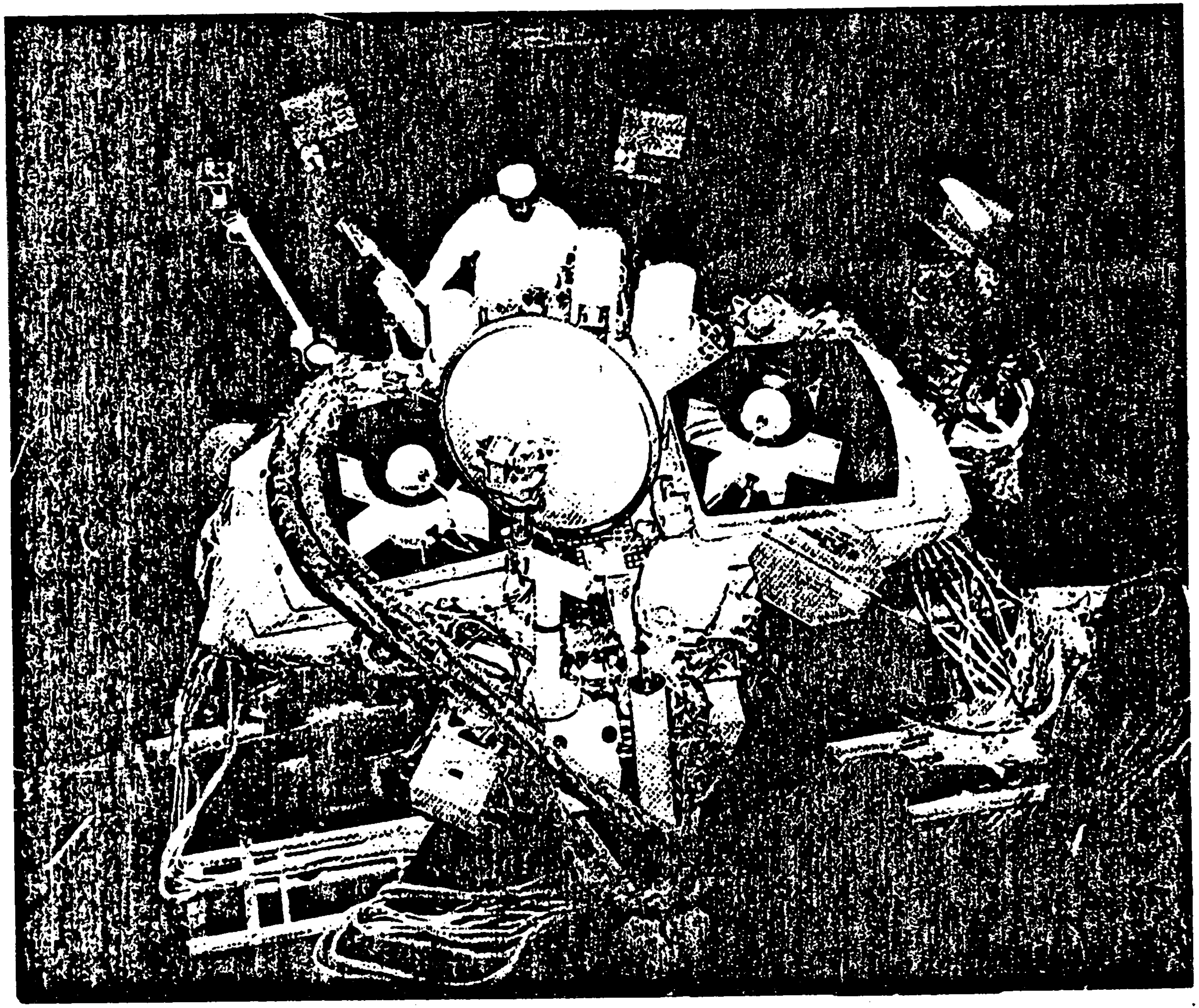
- Windscreens were used to protect the RTGs from being super-cooled by high winds and to reduce the effects on the generators of Martian dust-storms.

- The Viking SNAP-19 RTGs worked well on Mars, far exceeding their one-year life requirement on the planet. One signal was lost after 3 years when the antenna was misaligned. The other signal was lost after 6 years when the orbiter relay vehicle ran out of gas for attitude control.

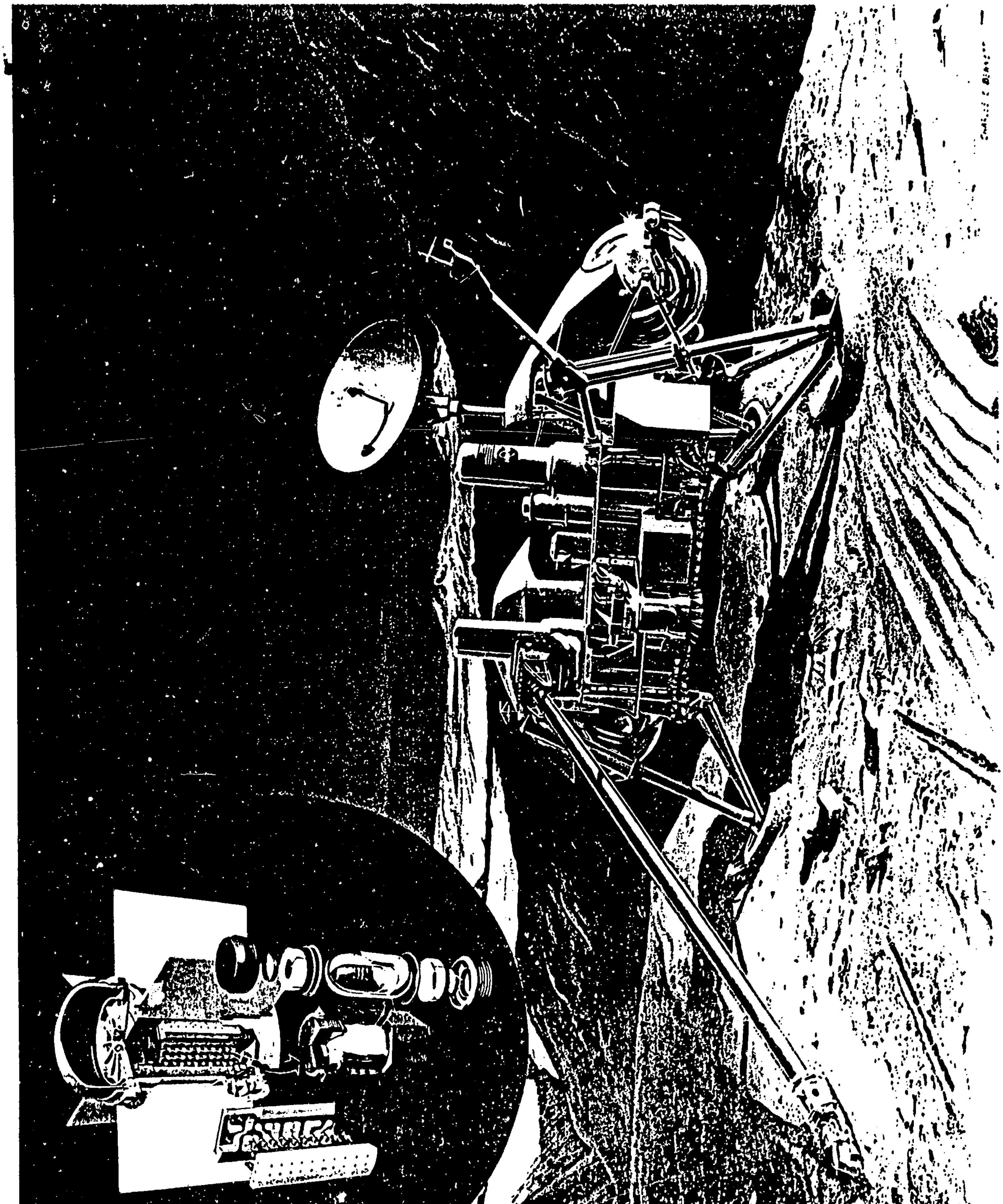
- The Viking experience would be directly applicable to the integration of RTGs into a soft lander vehicle for the Moon or Mars.

10.

SNAP-19 RTG INTEGRATION TEST ON VIKING LANDER



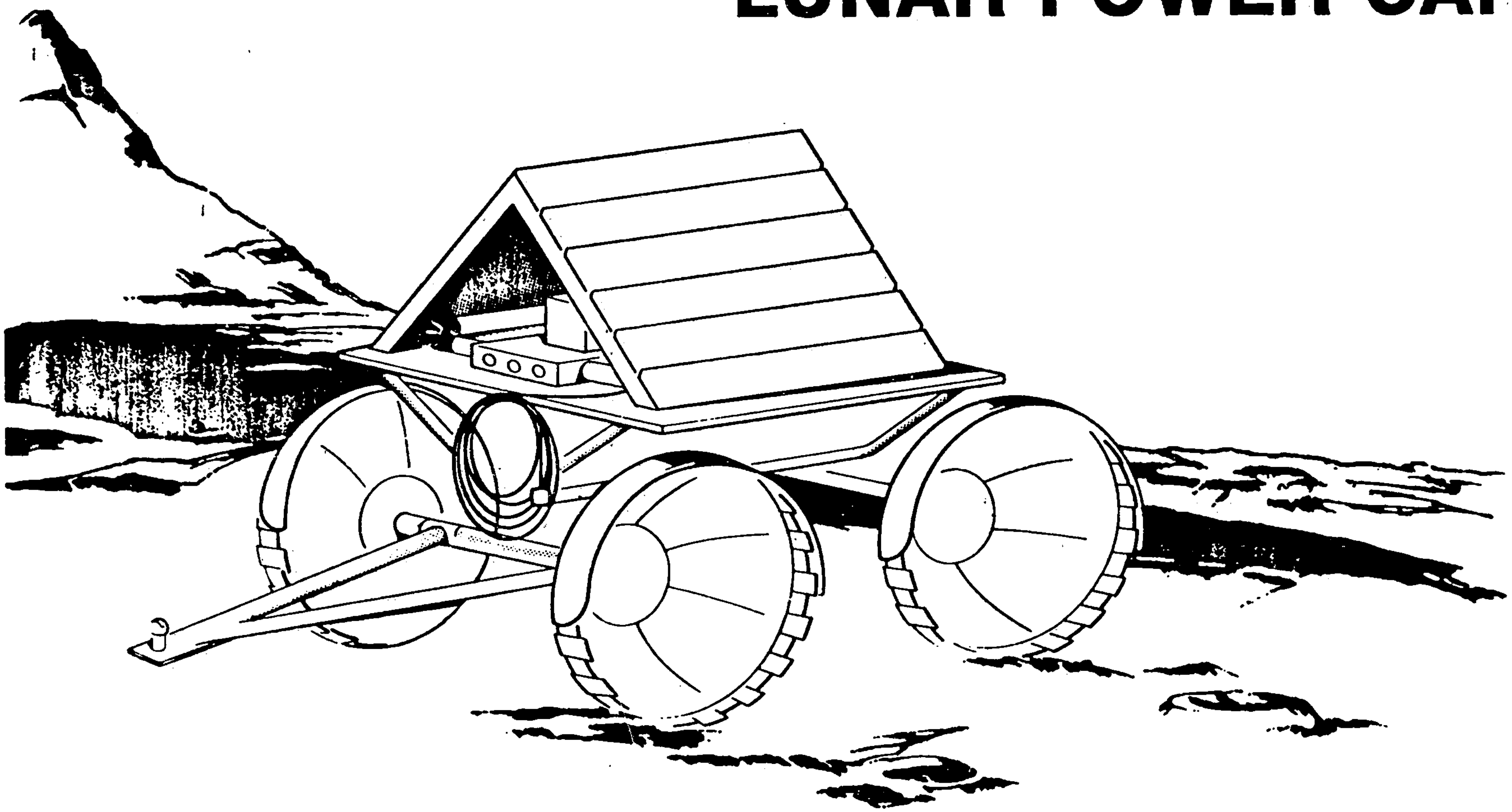
TP2733



LESSONS LEARNED FROM PAST PROGRAMS

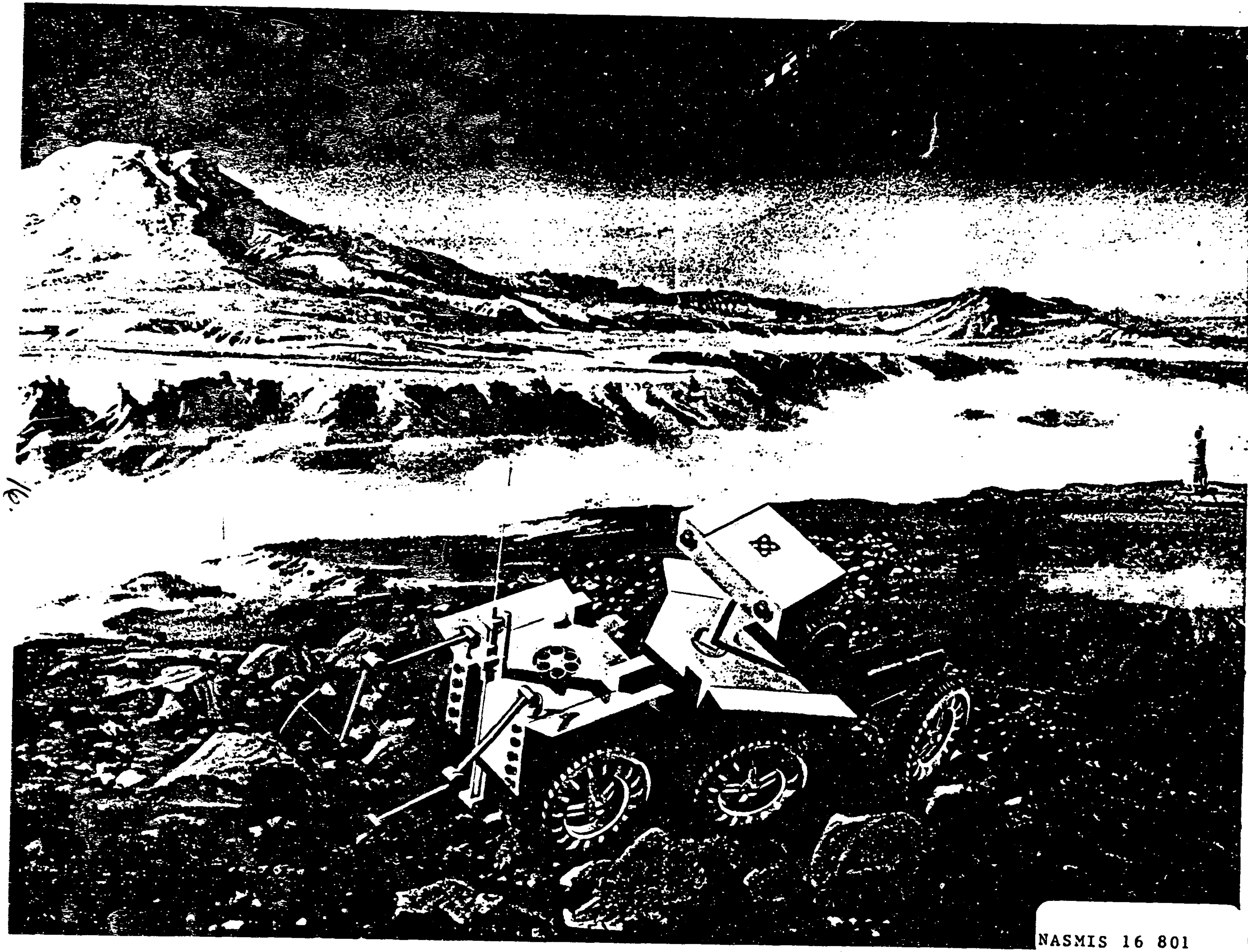
- RTGs provide reliable, long-lived power sources for Lunar and Martian surface equipment.
- Waste heat from RTGs provide thermal control of electronic equipment so it will survive cold night-time conditions.
- Planning for the use of RTGs from the very first mission will reduce spacecraft design and qualification costs and provide more science returned from the earlier mission investments.
- Although RTGs are not inexpensive, they provide a favorable cost trade-off for Lunar surface missions on a total mission cost (including launch costs) basis.
- Integrally fueled RTGs can be safely launched on unmanned Lunar and planetary surface science missions with minimal risks to operating personnel, the general public and the environment.

LUNAR POWER CART



RADIOISOTOPE THERMOELECTRIC GENERATORS (RTGs)

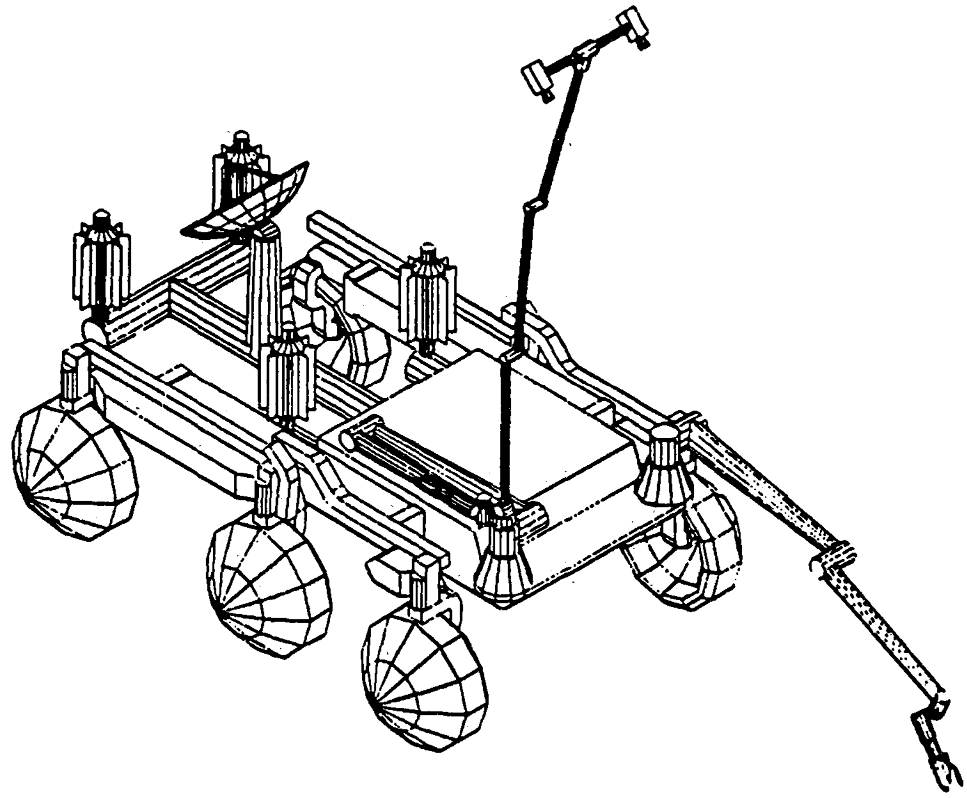
- For power levels up to hundreds of watts (e) per RTG.
- TAGS RTGS (similar to those used for SNAP-11, SNAP-19, SNAP-27) operated on Pioneer 10 and 11 for nearly 20 years.
- SiGe RTGs used on LES 8/9, Voyager 1/2, Galileo, and Ulysses are being fabricated for CRAF/Cassini.
- TAGS/SiGe multicouple technology under development for modular RTGs useful over a wide power range.
- Conceptual design studies for new missions:
  - Mars Global Network Instrument Packages
  - Mars Rover Power Units
  - Mars Sample Return Lander Power Units



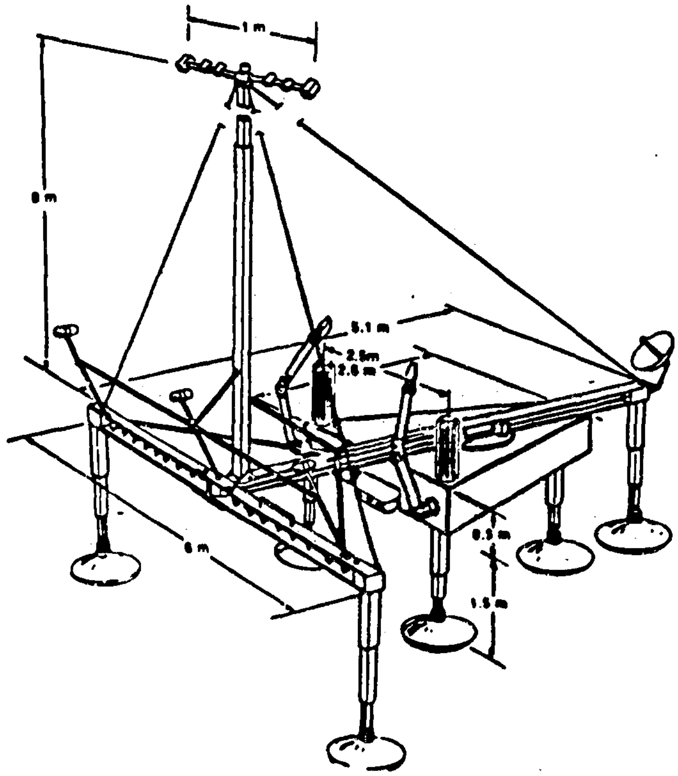
16.

ILLUSTRATIVE ROVER DESIGN OPTIONS

Wheeled Vehicle with Four 125-Watt RTGs



Walking Beam Vehicle with Two 250-Watt RTGs



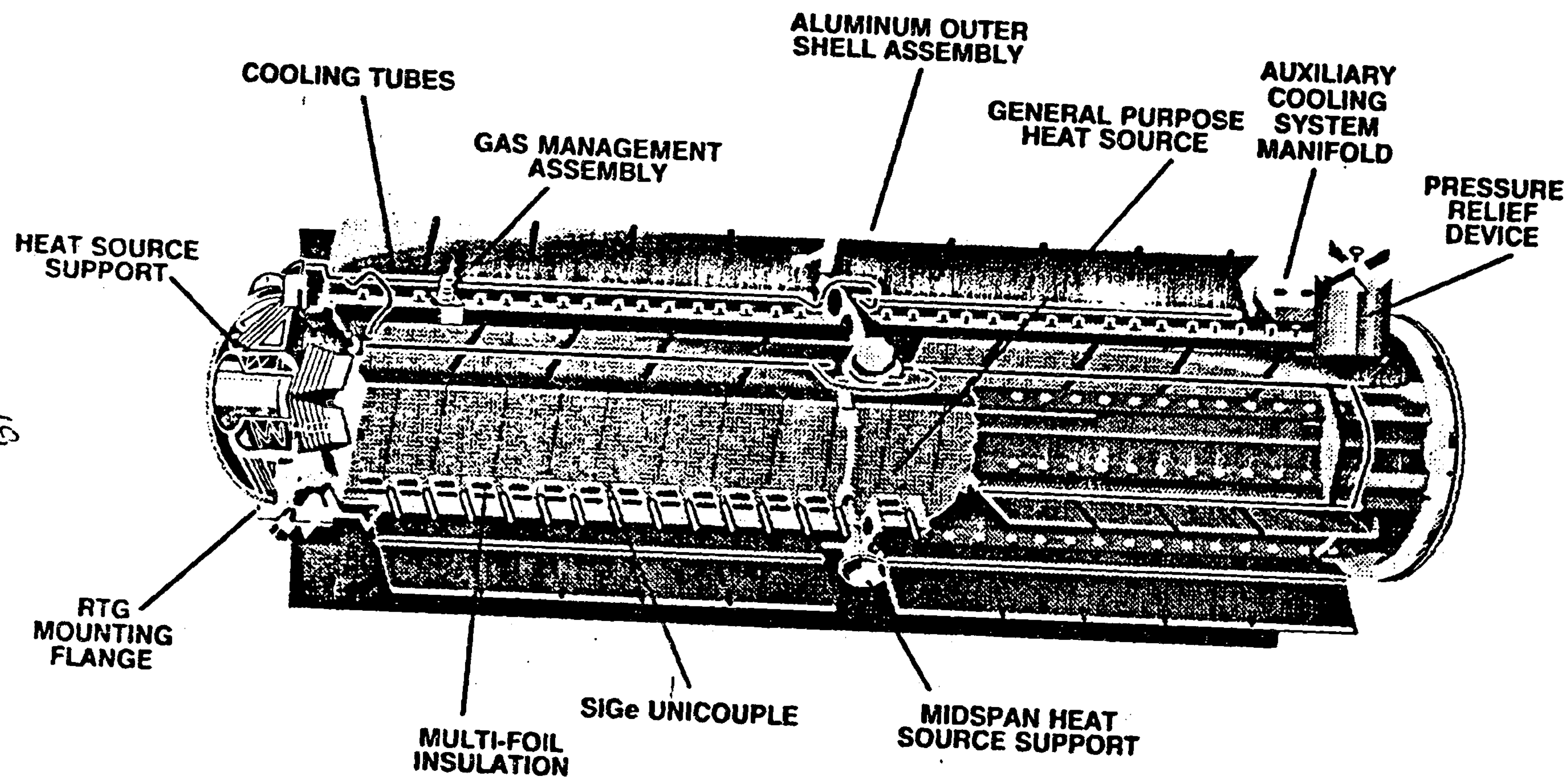
THE USE OF NUCLEAR ELECTRIC POWER ON SPACECRAFT PROVIDES

- OPERATIONAL BENEFITS
  - LONG OPERATIONAL LIFETIMES
  - HIGH RELIABILITY
  - COMPACT SIZE
  - GOOD POWER TO MASS RATIO
  - GOOD SPACECRAFT ATTITUDE CONTROL
  - GOOD SPACECRAFT STRUCTURAL COMPATABILITY
  - SOURCE OF HEAT FOR TEMPERATURE CONTROL
- ENVIRONMENT INDEPENDENT
- SPACECRAFT SELF-SUFFICIENCY

18.

GENSA 01 403

GENERAL PURPOSE HEAT SOURCE - RADIOISOTOPE THERMOELECTRIC GENERATOR



- **POWER OUTPUT** - 285 WATTS
- **FUEL LOADING** - 4400 WT; 132,500 Ci
- **WEIGHT** - 124 LBS
- **SIZE** - 16.6 IN × 44.5 IN

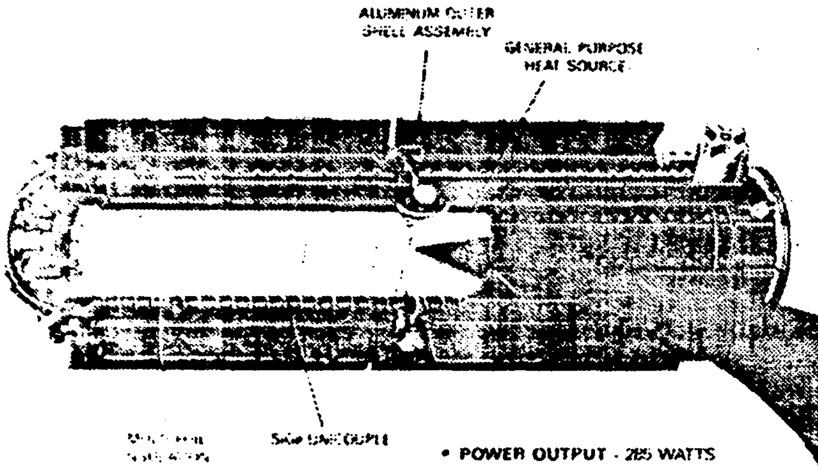
RL 0326

GENERAL PURPOSE HEAT SOURCE (GPHS) MODULE

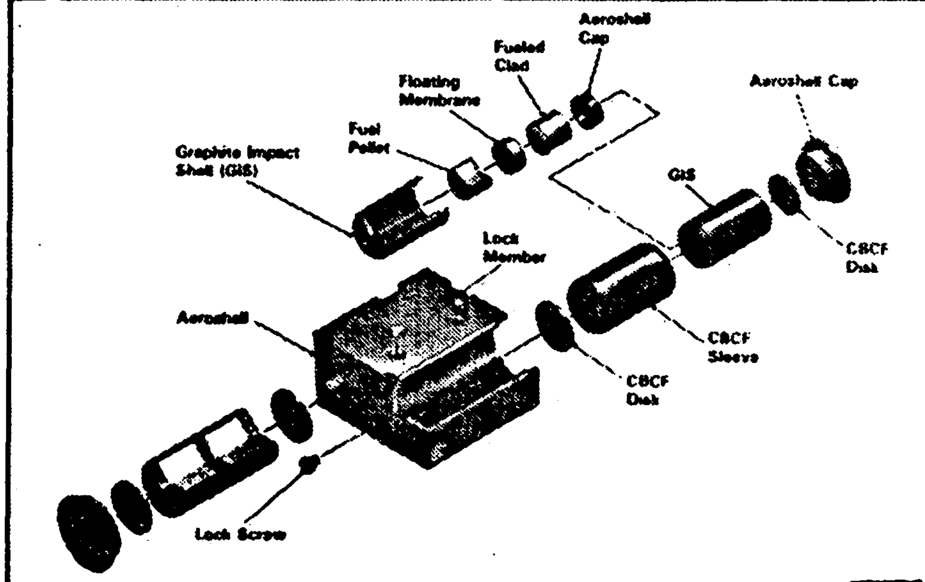
- Used on Shuttle launched Galileo and Ulysses missions.
- More being fabricated and qualified for the Titan-IV-Centaur launched CRAF/Cassini missions.
- Modular (250 Wt per module) heat source which can be used for RTGs or DIPS.
- Safety qualification for CLL only requires incremental analyses/tests to cover any unique mission abort environments.

GENERAL PURPOSE HEAT SOURCE

RADIOISOTOPE THERMOELECTRIC GENERATOR

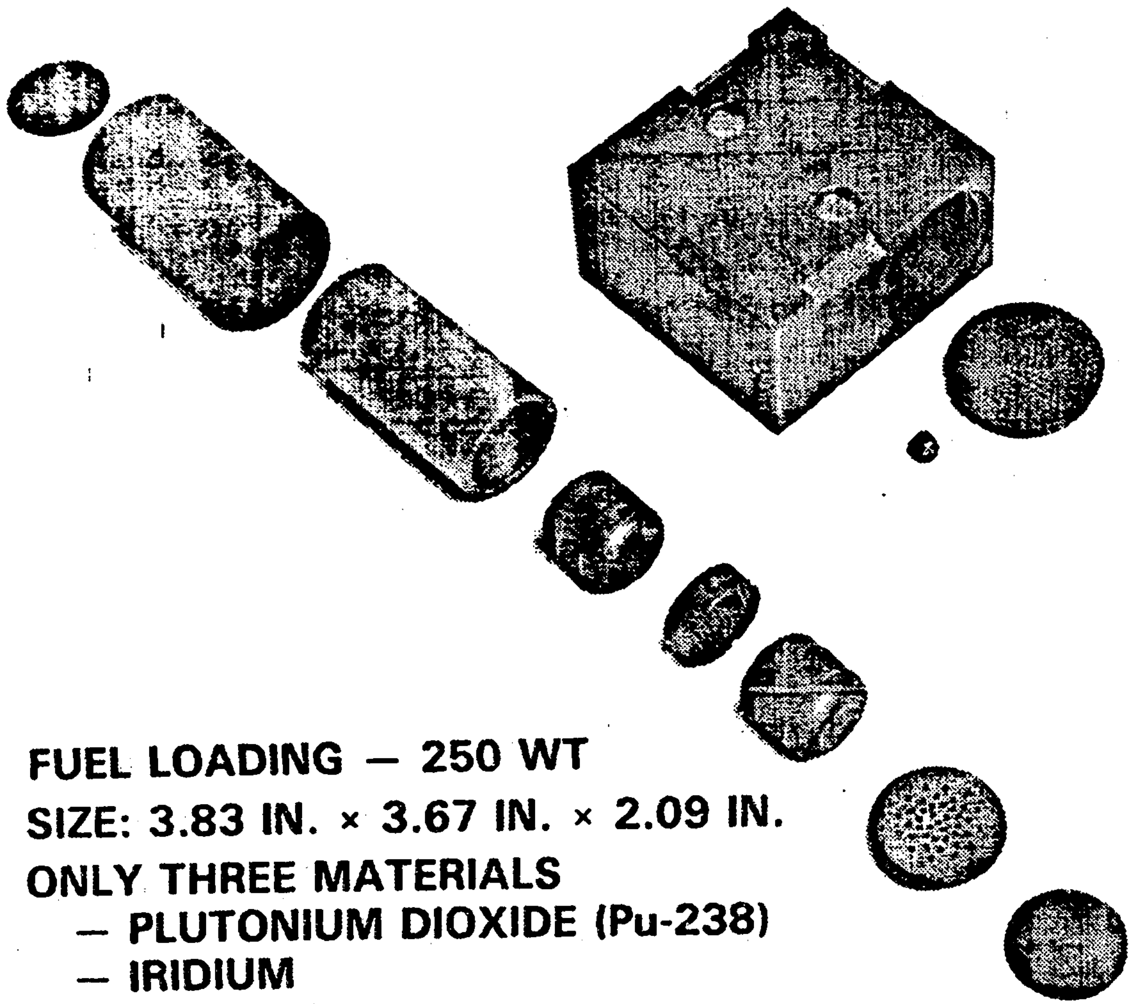


- POWER OUTPUT - 285 WATTS
- FUEL LOADING - 4400 WT, 132,500 CI
- WEIGHT - 124 LBS
- SIZE - 16.6 IN x 44.5 IN



21

GENERAL PURPOSE HEAT SOURCE (GPHS)



FUEL LOADING — 250 WT

SIZE: 3.83 IN. × 3.67 IN. × 2.09 IN.

ONLY THREE MATERIALS
- PLUTONIUM DIOXIDE (Pu-238)
- IRIDIUM
- GRAPHITE

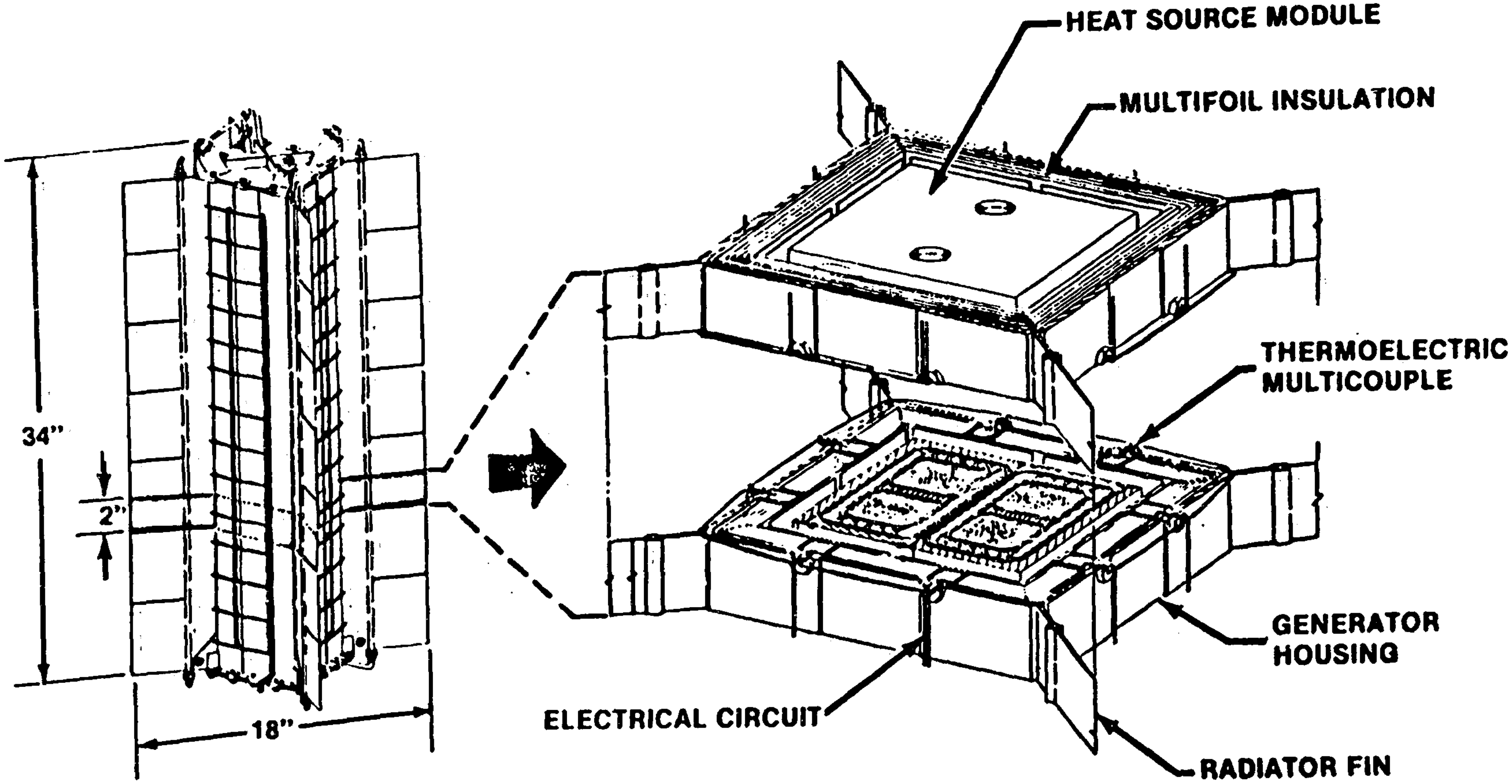
RTG 12 112

22

MITG (MODULAR ISOTOPIC THERMOELECTRIC GENERATOR)

ILLUSTRATIVE GENERATOR
14 Slices, 288 Watts, 68 Lbs., 4.25 W/Lb

MODULAR SLICE
(20.5 Watts at 28 Volts)



RTG 11 501

MOD-RTG Reference Flight Design

Design Attributes

Modularized Power Output	19 watts to 340 watts
Active Cooling System (ACS)	Satisfies launch vehicle reqts
Pressure Relief Device (PRD)	Vents cover gas to space

Performance (18 GPHS module design)

Voltage	30.8 volts
Power Output	340 watts
Specific Power	7.7 watts/kg
Converter Efficiency	7.6%

Physical Characteristics (18 GPHS module design)

Length	1.08m
Overall Diameter	0.33m
Weight (incl. positive bias comp.)	44.2 kg
Number of GPHS Modules	18
Number Multicouples	144

RTG 11 107

201

DYNAMIC ISOTOPE POWER SYSTEMS (DIPS)

- For power levels above 1 kWe (higher efficiency, easier integration).
- 1.3 kWe Organic Rankine systems demonstrated in the 1970's.
- 2.5 kWe Module Brayton System under development.
- Stirling Cycle Systems technology under study.
- Conceptual Design Studies for SEI Lunar and Mars Surface Applications.


Future Space Nuclear Power Applications
DYNAMIC ISOTOPE
POWER SYSTEM
(DIPS)
MARINER MARK 2

DIPS 03 401


NASA
DIPS 08 113

PLUTONIUM-238 FUEL PRODUCTION

- DOE produces Pu-238 to meet firm future requirements from user agencies. Production to date has been in the DOE's Material Production reactors at Savannah River Site.

- It takes about 30 months to design and fabricate the Np-237 targets, irradiate the targets in the reactor(s), cool the targets and process the targets to recover the Pu-238 and recycle the Np-237.

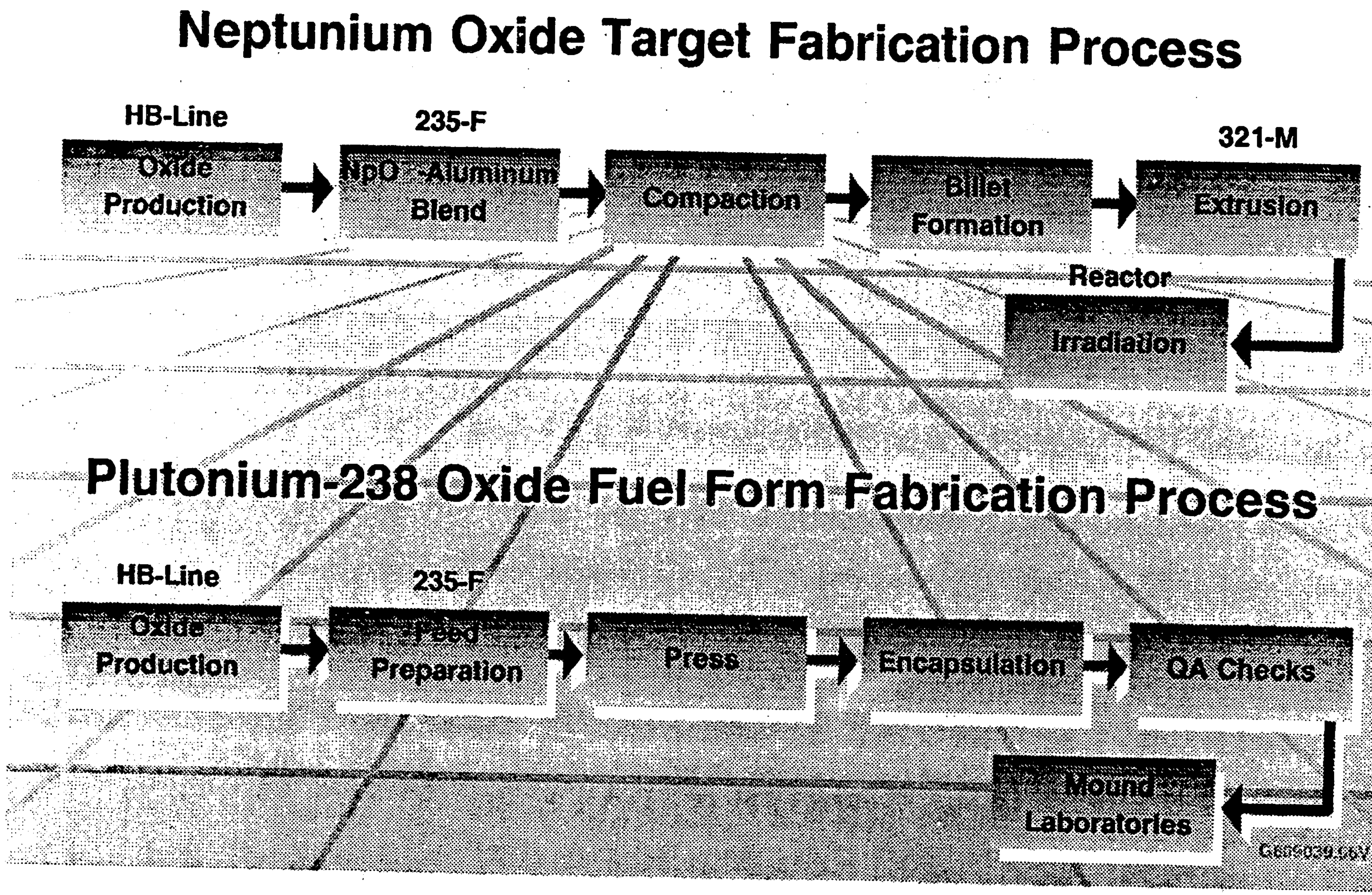
- No new Pu-238 fuel has been produced since the Savannah River production reactors were shut-down in 1989.

- The entire existing Pu-238 inventory is being recovered and blended for 5 new RTG heat sources and small heater units for the CRAF/Cassini missions.

- Current restart plans for the SR reactors could provide new Pu-238 fuel starting in 1994.

- Present plans call for producing Pu-238 at an annual rate of 15 kg (~600 We of RTGs). Production rates can be altered to meet requirements if given sufficient lead time.

- A new funding policy for the costs of producing Pu-238 is currently under negotiation between NASA and DOE.


Neptunium Oxide Target Fabrication Process
HB-Line
Oxide Production
235-F
NpO -Aluminum Blend
Compaction
Billet Formation
321-M
Extrusion
Reactor
Irradiation
Plutonium-238 Oxide Fuel Form Fabrication Process
HB-Line
Oxide Production
235-F
Feed Preparation
Press
Encapsulation
QA Checks
Mound Laboratories

INITIATION OF A NEW RTG PROGRAM

- o Request for support from NASA to DOE

- o Long lead-time planning
  - Budgets
  - Preprocurement Activities
  - Pu-238 Production
  - Interagency Agreements
  - Nuclear Facilities

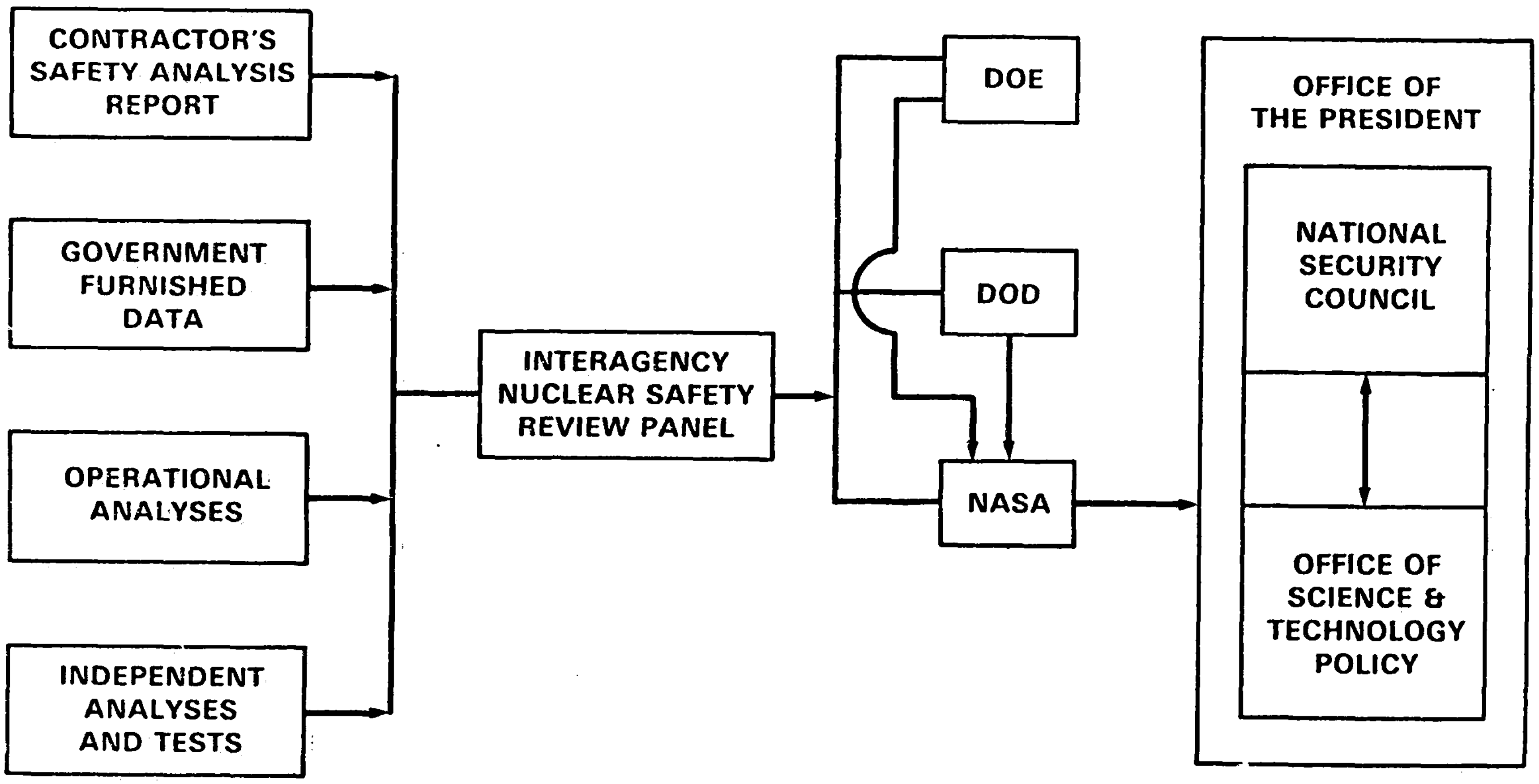
- o Early DOE Support
  - Project Office Liaison
  - Conceptual Designs
  - Spacecraft Integration
  - EIS Inputs
  - Program Schedule and Costs

- o After NASA Program Approval
  - Interagency Requirements Established
  - Award Non-nuclear Hardware Contract(s)
  - Provide Guidance to DOE Laboratories

INTERAGENCY NUCLEAR SAFETY REVIEW PANEL

- NASA, DOE & DOD SAFETY REPRESENTATIVES
- REVIEWS DOE'S SAFETY ANALYSIS REPORT
- PREPARES SAFETY EVALUATION REPORT
  - WHITE HOUSE/OFFICE OF SCIENCE & TECHNOLOGY POLICY APPROVES LAUNCH

SAFETY APPROVAL PROCESS



SAFETY 02 101

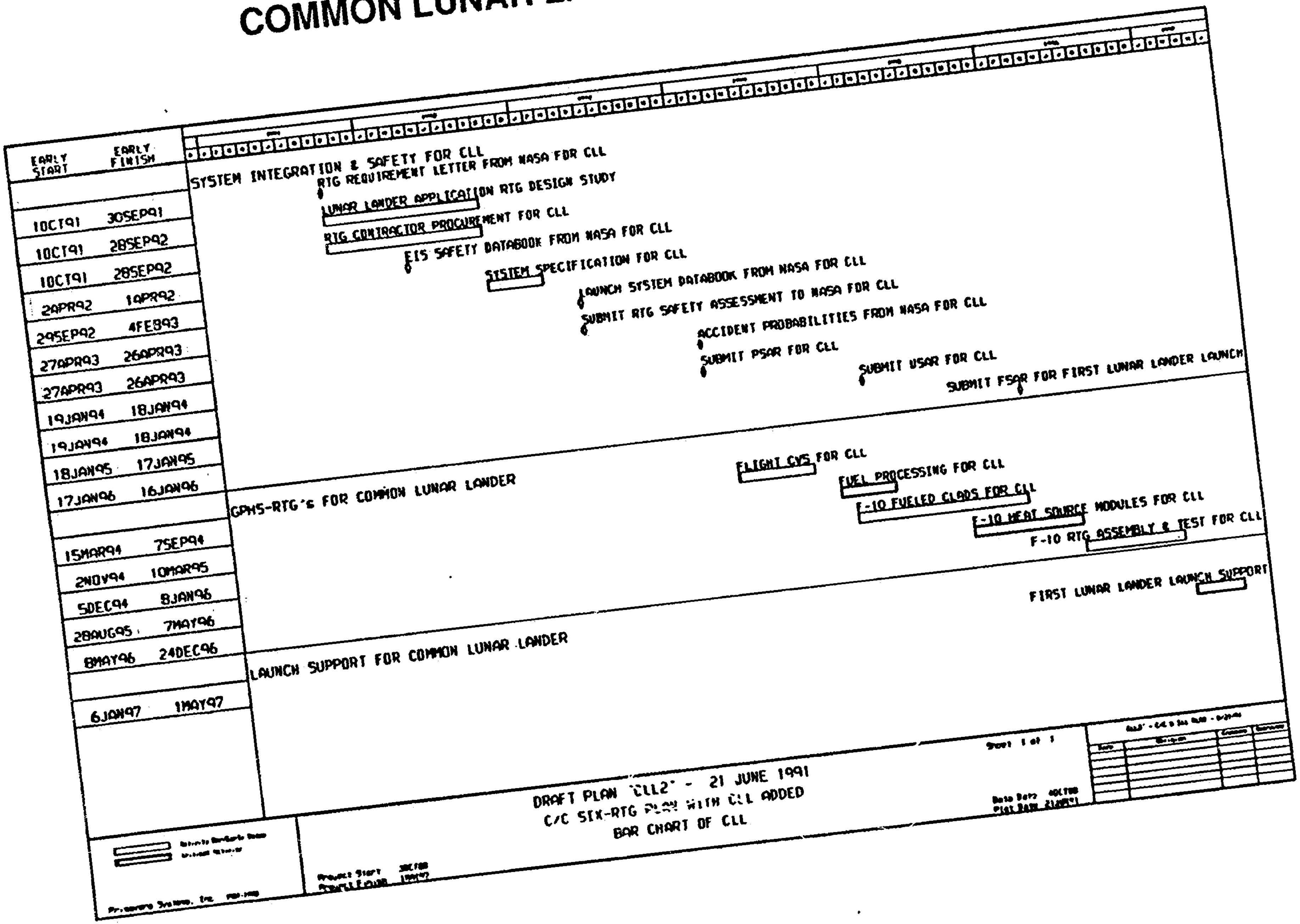
RTG PROGRAM OPTIONS FOR THE CLL

- If it can be shown that a 300 We GPHS-RTG can be used for CLL, CRAF/Cassini production lines can be continued as shown on this schedule. This would support a launch in May 1997 and would cost NASA about $30M (not including fuel).

- If a new RTG must be designed and qualified for the CLL missions, it would take 4-5 years after program (budget) approval to deliver flight units. The cost to NASA would depend on the type, size, and number of RTGs required.

- Small Radioisotope Heater Units (RHUs) can be delivered on a somewhat shorter schedule at a cost of $10-20,000 per watt (t).

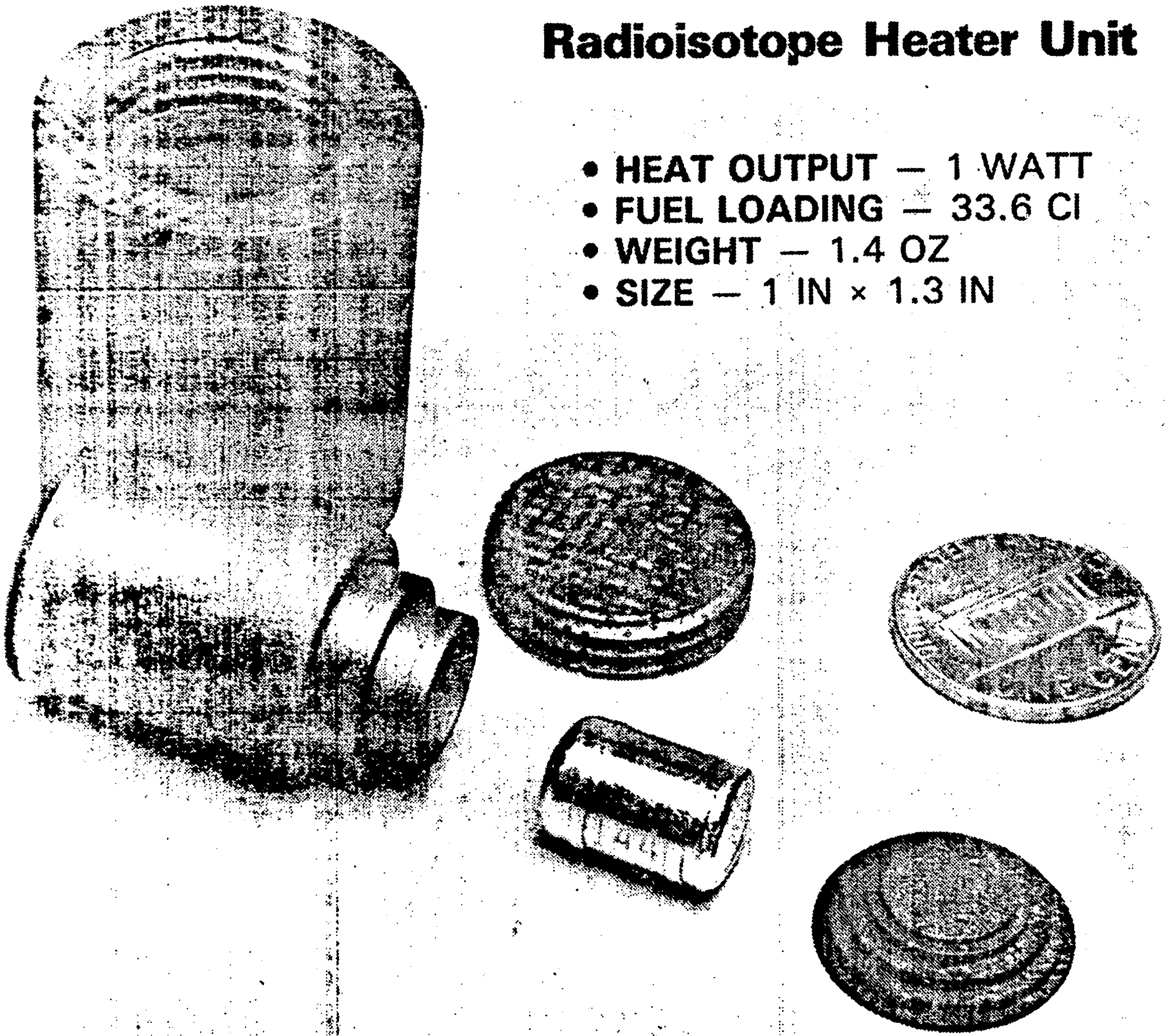
SCHEDULE FOR PROVIDING F-10 RTG TO COMMON LUNAR LANDER PROGRAM



34

Radioisotope Heater Unit

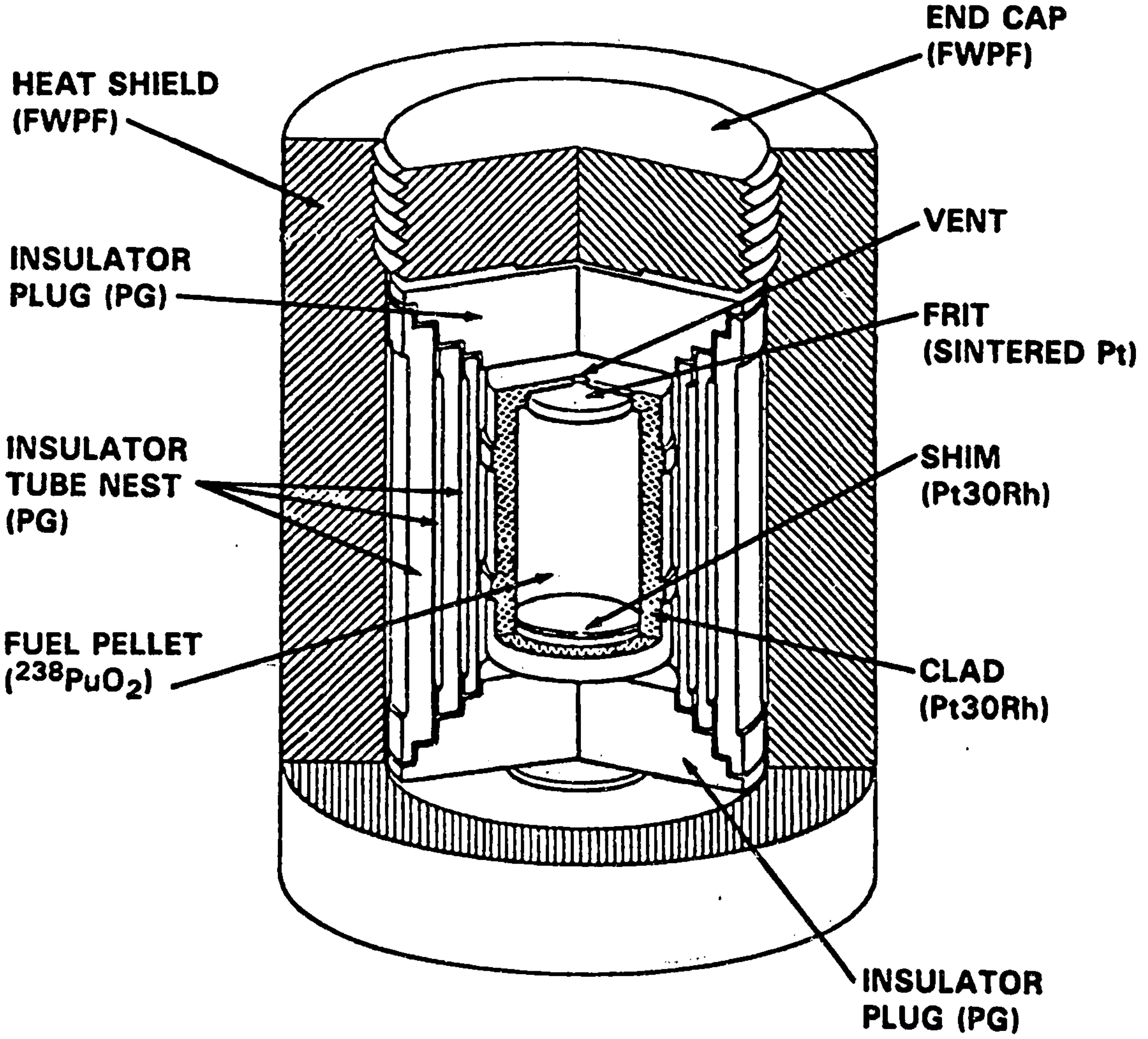
- HEAT OUTPUT — 1 WATT
- FUEL LOADING — 33.6 CI
- WEIGHT — 1.4 OZ
- SIZE — 1 IN × 1.3 IN



RTG 15 801

Figure 3

LIGHTWEIGHT RADIOISOTOPE HEATER UNIT



Materials:

FWPF - Fine Weave Pierced Fabric Graphite
PG - Pyrolytic Graphite
Pt30Rh - Platinum - 30 Percent Rhodium Alloy

INTERAGENCY AGREEMENTS

- A Memorandum of Understanding (MOU) between NASA and DOE is presently in place which defines the roles of the two agencies for space missions using Radioisotope Power Systems (RPS).

- A supplement to this MOU can be added to specifically address the needs of the Common Lunar Lander Program.

- A more specific Program Management Agreement is normally drawn up between the NASA Project Office (JSC) and the DOE Office of Special Applications to implement the interagency responsibilities pertaining to the RPS.

- Early in the program, a Technical Interface Specification is used to set forth the spacecraft-RPS interface requirements.

ADVANCED RADIOISOTOPE POWER SYSTEMS PROGRAM

RTG TYPICAL COST DISTRIBUTION

- **USER PAYS:**
  - RTG PRELIMINARY AND FINAL DESIGN AND ANALYSES
  - CONVERTER PRODUCTION LINE QUALIFICATION AND PRODUCTION
  - HEAT SOURCE FABRICATION AND ASSEMBLY
  - RTG FUELING
  - RTG ACCEPTANCE TESTING
  - RTG GROUND SUPPORT EQUIPMENT
  - RTG MODELS/SIMULATORS
  - QUALIFICATION UNIT DESIGN, HARDWARE AND TESTING
  - INTERFACE SUPPORT
  - GROUND SAFETY ANALYSES
  - PLUTONIUM-238 PRODUCTION AND PROCESSING

CONCLUSIONS

- Radioisotope Power System technology and supporting facility capabilities exist within the DOE to fabricate and flight qualify power units concurrently with (and properly integrated with) the design and development of the Common Lunar Lander spacecraft.

- Radioisotope Power Systems developed for Lunar surface missions can also be used for Martian surface missions (if proper considerations are given to differences in the operating environments).

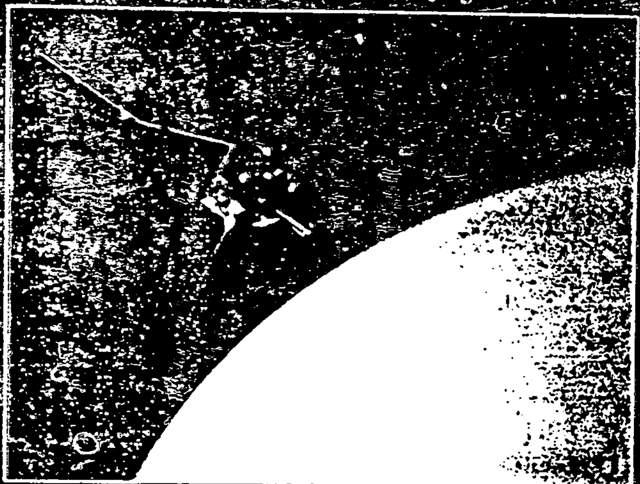
- The next step in obtaining Radioisotope Power/Heat Sources for the Common Lunar Lander:
  - Formal expressions of interest by NASA
  - Technical interface coordination with DOE
  - Initiate Programmatic and Budget Cycle Planning.

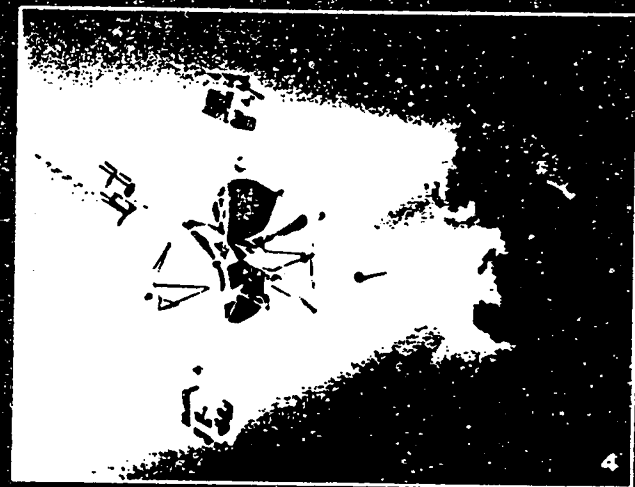
RTG TYPICAL COST DISTRIBUTION (Cont.)

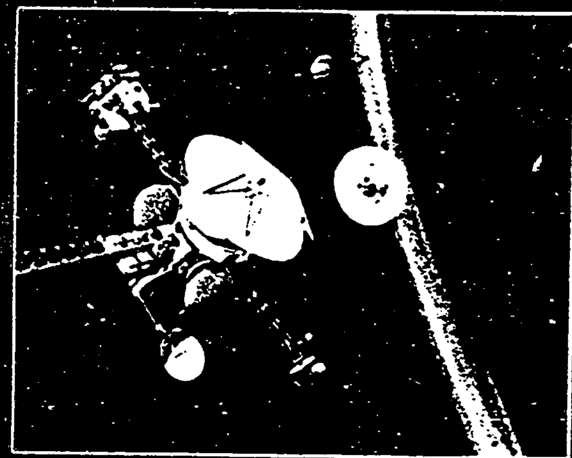
- **DOE PAYS:**

  - TECHNOLOGY DEVELOPMENT AND CONCEPTUAL DESIGN
  - ENGINEERING UNIT DESIGN, HARDWARE AND TESTING
  - HEAT SOURCE DEVELOPMENT AND QUALIFICATION
  - HEAT SOURCE PRODUCTION LINE QUALIFICATION
  - HEAT SOURCE SAFETY TESTING
  - SAFETY ANALYSIS REPORTS
  - QUALITY ASSURANCE
  - FACILITY MAINTENANCE AND GENERAL PURPOSE EQUIPMENT
  - RTG SHIPPING CONTAINERS, SAFETY ANALYSES REPORT FOR PACKAGING AND TRANSPORTATION TO USER
  - EMERGENCY RESPONSE
  - PROGRAM MANAGEMENT

THE FUTURE IS NOW







1. Ulysses to the Sun
2. Conceptual Mars Rover
3. Galileo to Jupiter
4. Comet Rendezvous Asteroid Flyby
5. Cassini to Saturn

41

GENCORP
AEROJET

Propulsion Division

Lightweight High Performance Lunar Lander For Near Term Missions

42

M. C. McIlwain

2 July 1991

#91-27

LL MCM 7/2/91-C

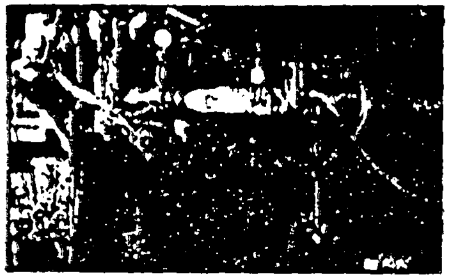
Aerojet's Strategic Defense Technology Can Be Adapted To Meet Near Term SEI Mission Requirements

- High Performance Engines
  - Platelet Injectors
  - Energetic Propellants
  - Composite Chambers/Nozzle
- Lightweight Components
  - 1240 psi Fuel Tank - 10 lbs.
  - 1240 psi Oxidizer Tank - 14 lbs.
  - 1200 psi He Tank - 66 lbs.
  - Axial Engine - 10 lbs.
- Fundamental Technologies; Fab and Performance Have Been Demonstrated

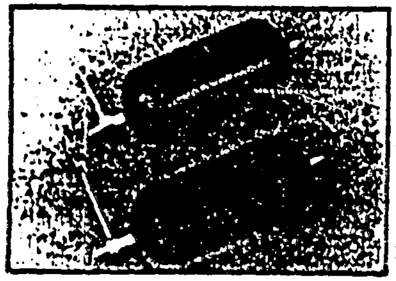
ALAS

Advanced Liquid Axial Stage

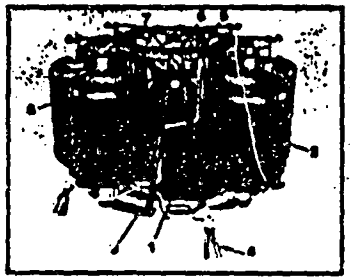
ALAS is Validating the Industry's Most Advanced Low Cost Liquid Propulsion Systems for Full Scale Development Initiation



- **120 Axial Engine Firings Demonstrated**
  - High Performance Propellants (CLF_5/N_2H_4)
  - Innovative Low Cost Platelet Fabrication
  - Lightweight Carbon Nozzle and Chamber

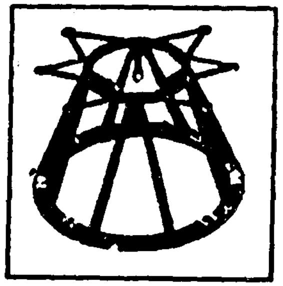


- **Burst Tested Pressurant and Propellant Tanks**
  - Demonstrated High Strength Carbon Overwrap
  - Validated Lightweight Thin Walled Aluminum Liners



1. High Performance Restartable Axial Engine
2. Carbon Overwrapped Al-Lined Tanks (4 Places)
3. 10,000 psia Helium Pressurant Bottle (2 Places)
4. 20 lbf ACS Engine (4 Places)
5. Inconel Heat Exchanger
6. Integrated Platelet Injector/Valve
7. Miniaturized Helium Regulator
8. Carbon Composite Structure

- **200 ACS Altitude Firings Demonstrated**
  - Ultra Lightweight Engines
  - Platelet Producibility Benefits
  - Low Cost Carbon Nozzles



- **Low Cost All-Composite Structure**
  - Mass Producible Injection Molded and Stamped Sheet Parts
  - Validated in 1990 by Boost Stage Demonstration

44

Aerojet's Strategic Defense Technology Can Be Adapted To Meet Near Term SEI Mission Requirements

- High Performance Engines
  - Platelet Injectors
  - Energetic Propellants
  - Composite Chambers/Nozzle

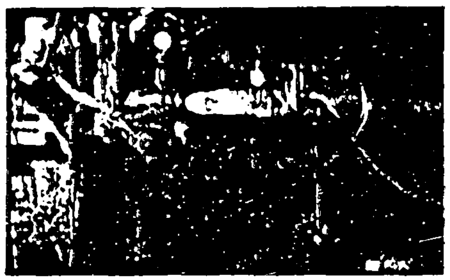
- Lightweight Components
  - 1240 psi Fuel Tank - 10 lbs.
  - 1240 psi Oxidizer Tank - 14 lbs.
  - 1200 psi He Tank - 66 lbs.
  - Axial Engine - 10 lbs.

- Fundamental Technologies; Fab and Performance Have Been Demonstrated

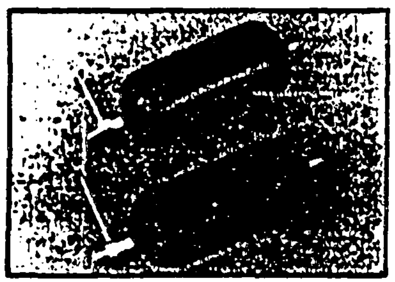
ALAS

Advanced Liquid Axial Stage

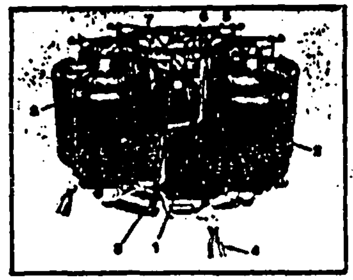
ALAS is Validating the Industry's Most Advanced Low Cost Liquid Propulsion Systems for Full Scale Development Initiation



- **120 Axial Engine Firings Demonstrated**
  - High Performance Propellants (CLF_5/N_2H_4)
  - Innovative Low Cost Platelet Fabrication
  - Lightweight Carbon Nozzle and Chamber

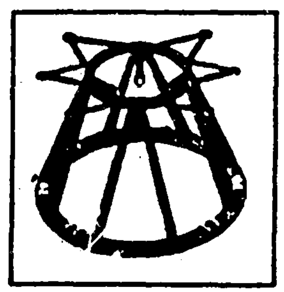


- **Burst Tested Pressurant and Propellant Tanks**
  - Demonstrated High Strength Carbon Overwrap
  - Validated Lightweight Thin Walled Aluminum Liners



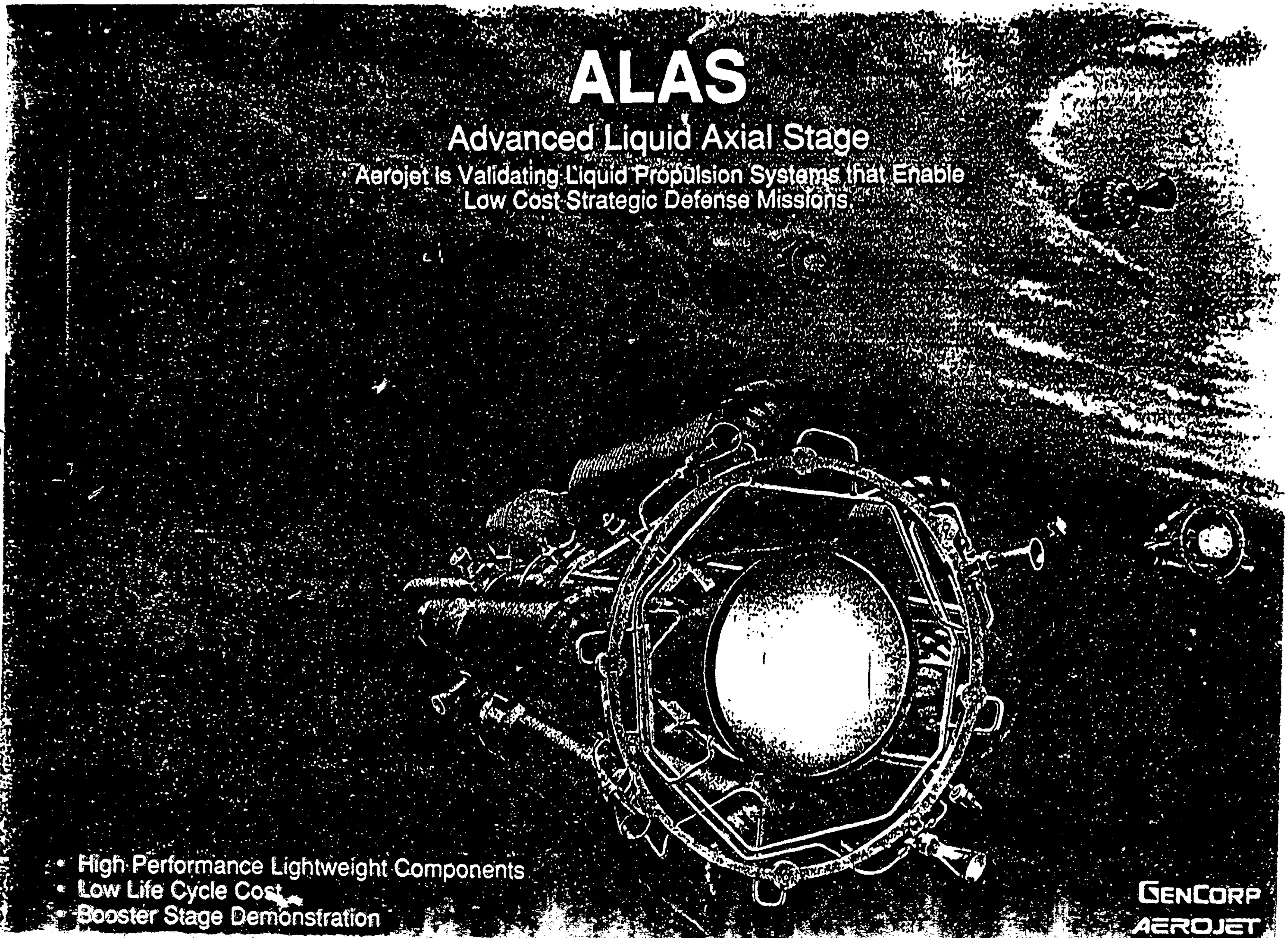
1. High Performance Restartable Axial Engine
2. Carbon Overwrapped Al-Lined Tanks (4 Places)
3. 10,000 psia Helium Pressurant Bottle (2 Places)
4. 20 lbf ACS Engine (4 Places)
5. Inconel Heat Exchanger
6. Integrated Platelet Injector/Valve
7. Miniaturized Helium Regulator
8. Carbon Composite Structure

- **200 ACS Altitude Firings Demonstrated**
  - Ultra Lightweight Engines
  - Platelet Producibility Benefits
  - Low Cost Carbon Nozzles



- **Low Cost All-Composite Structure**
  - Mass Producible Injection Molded and Stamped Sheet Parts
  - Validated in 1990 by Boost Stage Demonstration

46

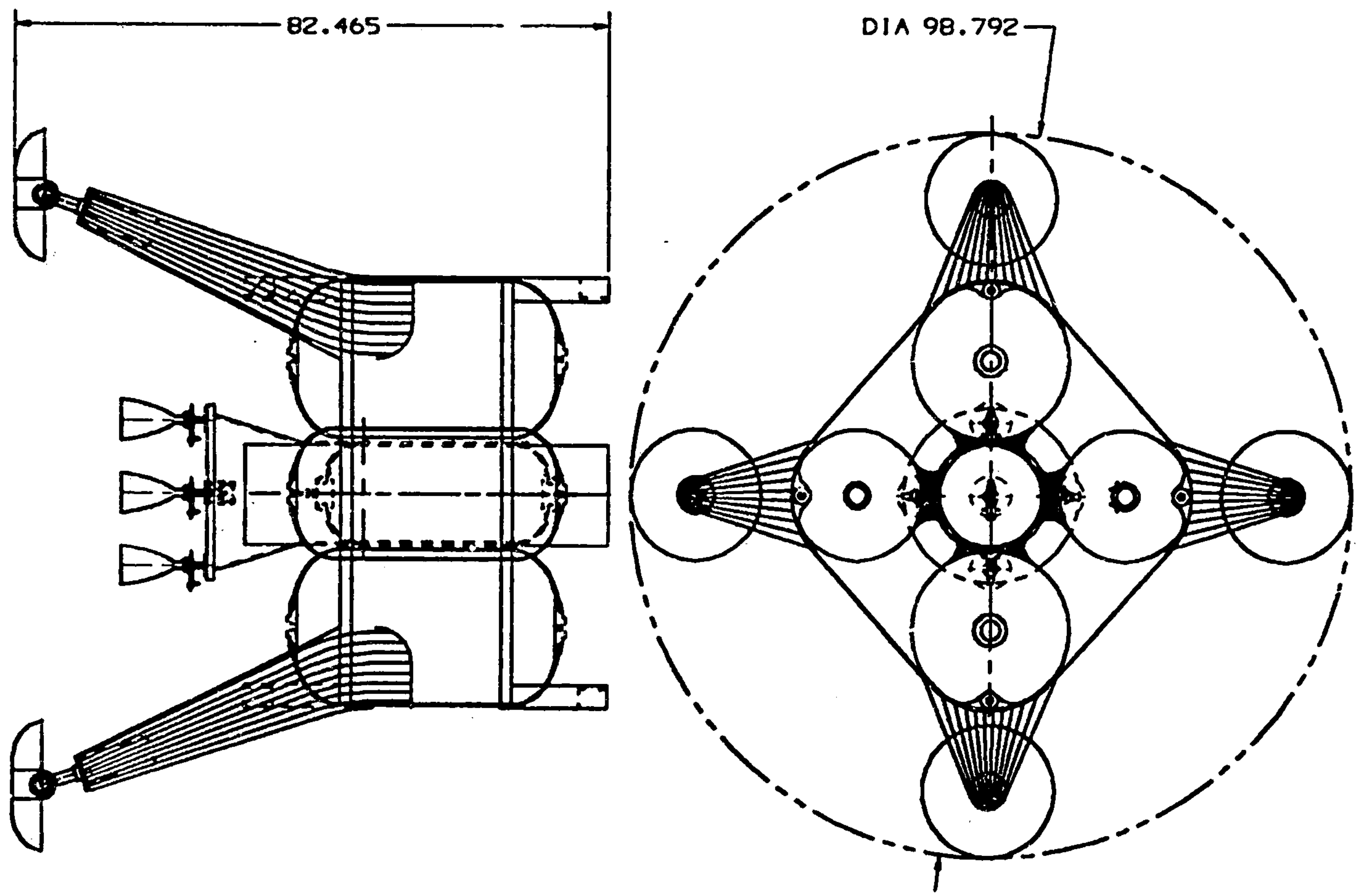

ALAS
Advanced Liquid Axial Stage
Aerojet is Validating Liquid Propulsion Systems that Enable Low Cost Strategic Defense Missions
• High Performance Lightweight Components
• Low Life Cycle Cost
• Booster Stage Demonstration
GENCORP
AEROJET

48.

Mission Assumptions for ALAS Based Lunar Lander

- Initial Mass of Stage + Payload - 1320 Kg
- Stage Function Lunar Orbit Capture & Landing Only
    - 1100 m/s for Orbital Braking (1G)
    - 2200 m/s for Landing (1/12G)
- Active Mission Duration - 2 hours
- Thrust Vector Control by Gimballing
    - Roll Control by Cold Gas System in Payload
- Five Engines Used for Braking
- One Throttling Engine (2:1) Used for Landing

ALAS Type Components Produce Compact High Performance Stage



LL MCM 7/2/91-08

Both High Performance & Conventional Storable Propellants Meet Payload Requirements

	High Perf.
Total Impulse (sec)	672,000
Total Burn Time (sec)	80/800
Propellants	ClF_5/N_2H_4
Feed System	P.ess. Fed HEX Aug.
Chamber Pressure, psi	750
Performance, sec	344
No. Engine	
Axial	5
Tanks	Graphite Epoxy Overwrapped Al tank
Structure	Graphite Epoxy or Graphite Bismalamide
Payload + Avionics, Kg	426*

*Reduced ~15% if N_2O_4/MMH propellant used

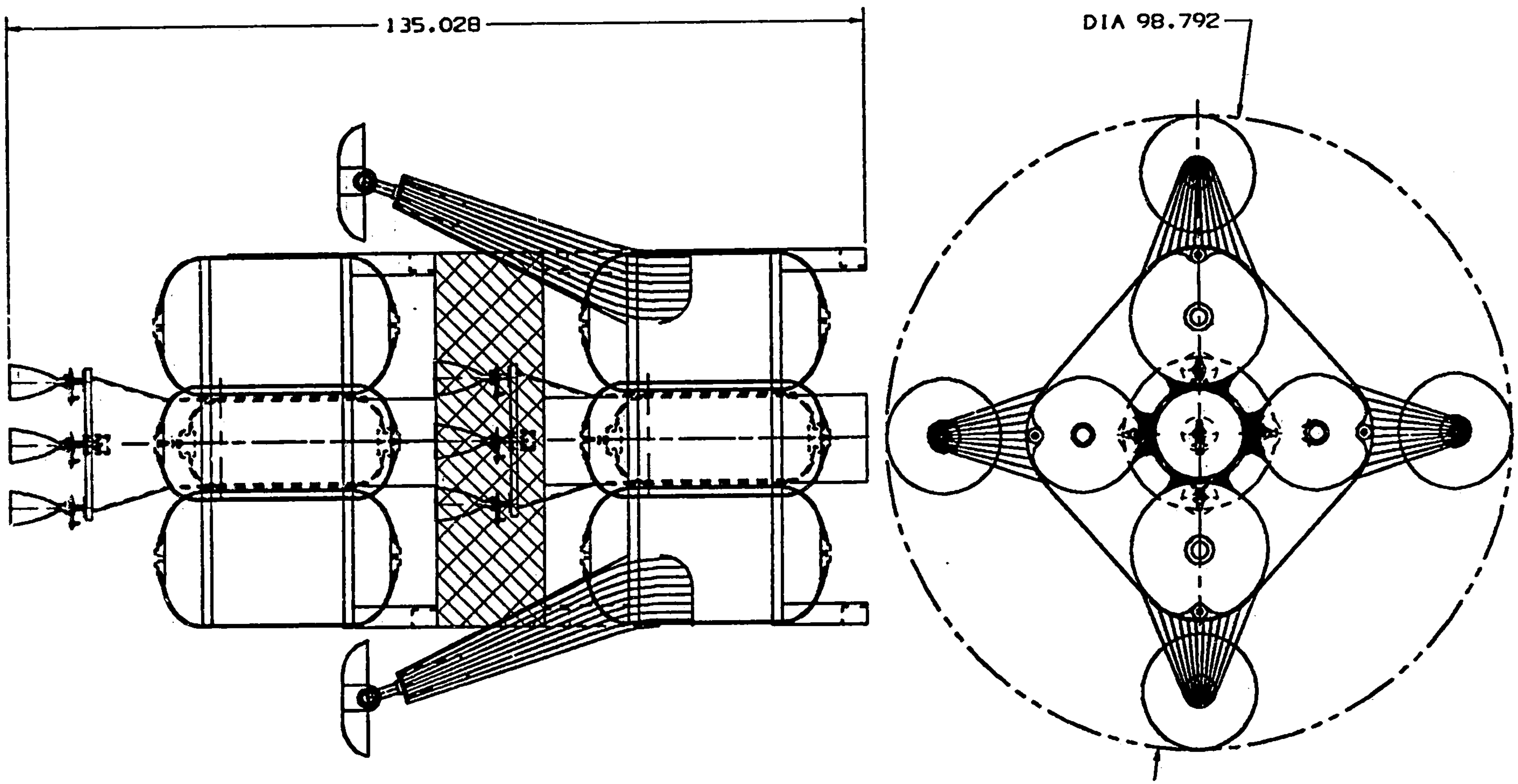
LL MCM 7/2/91-06

5d

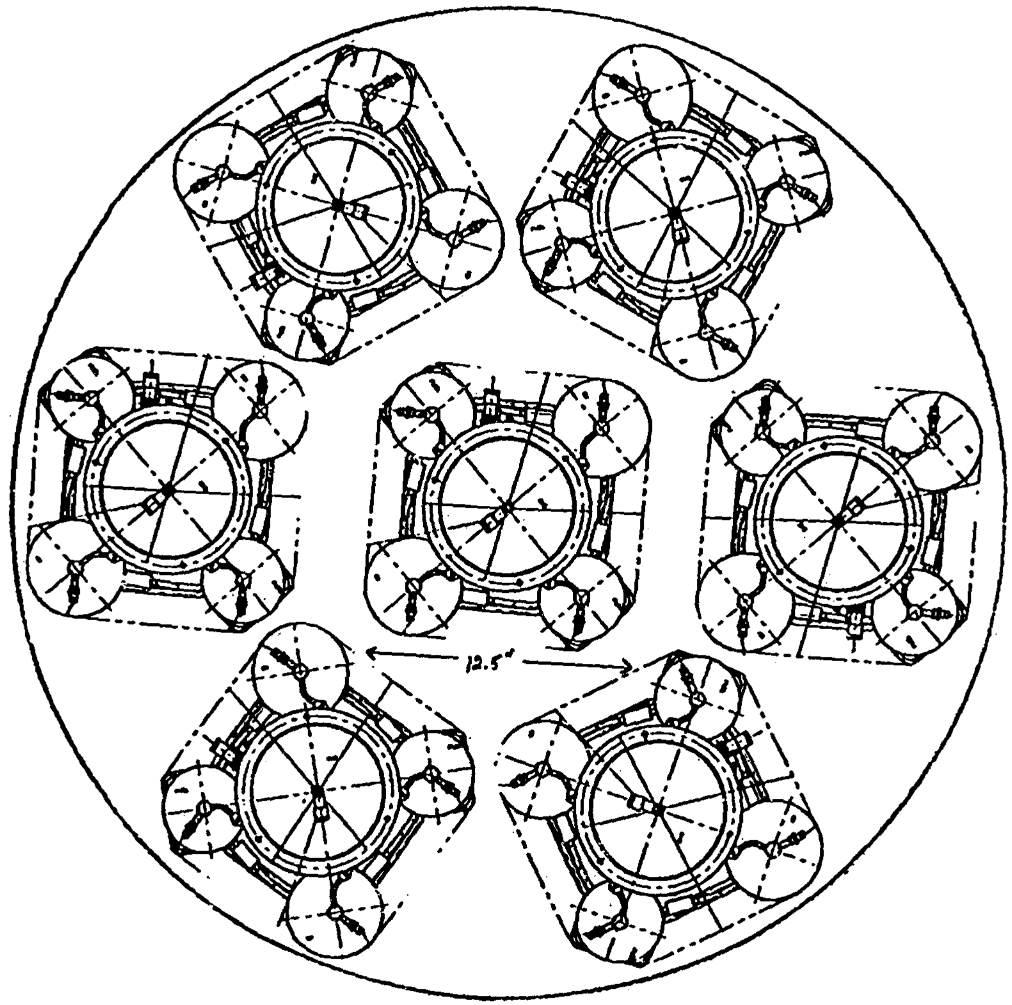
Two-Stage Lander Can Be Launched With Atlas AS

- Initial Mass of Stage + Payload - 2600 Kg
- First Stage Brakes for Lunar Orbit Capture
  - 1100 m/s for Orbital Braking (1G)
- Second Stage Executes Landing
  - 2200 m/s for Landing (1/12G)
- Active Mission Duration - 2 hours
- Stages Identical Except for Avionics and Landing Gear
- Thrust Vector Control by Gimballing
- Payload = 814 Kg

Two-Stage Lander Uses Common Core Stages & Avionics

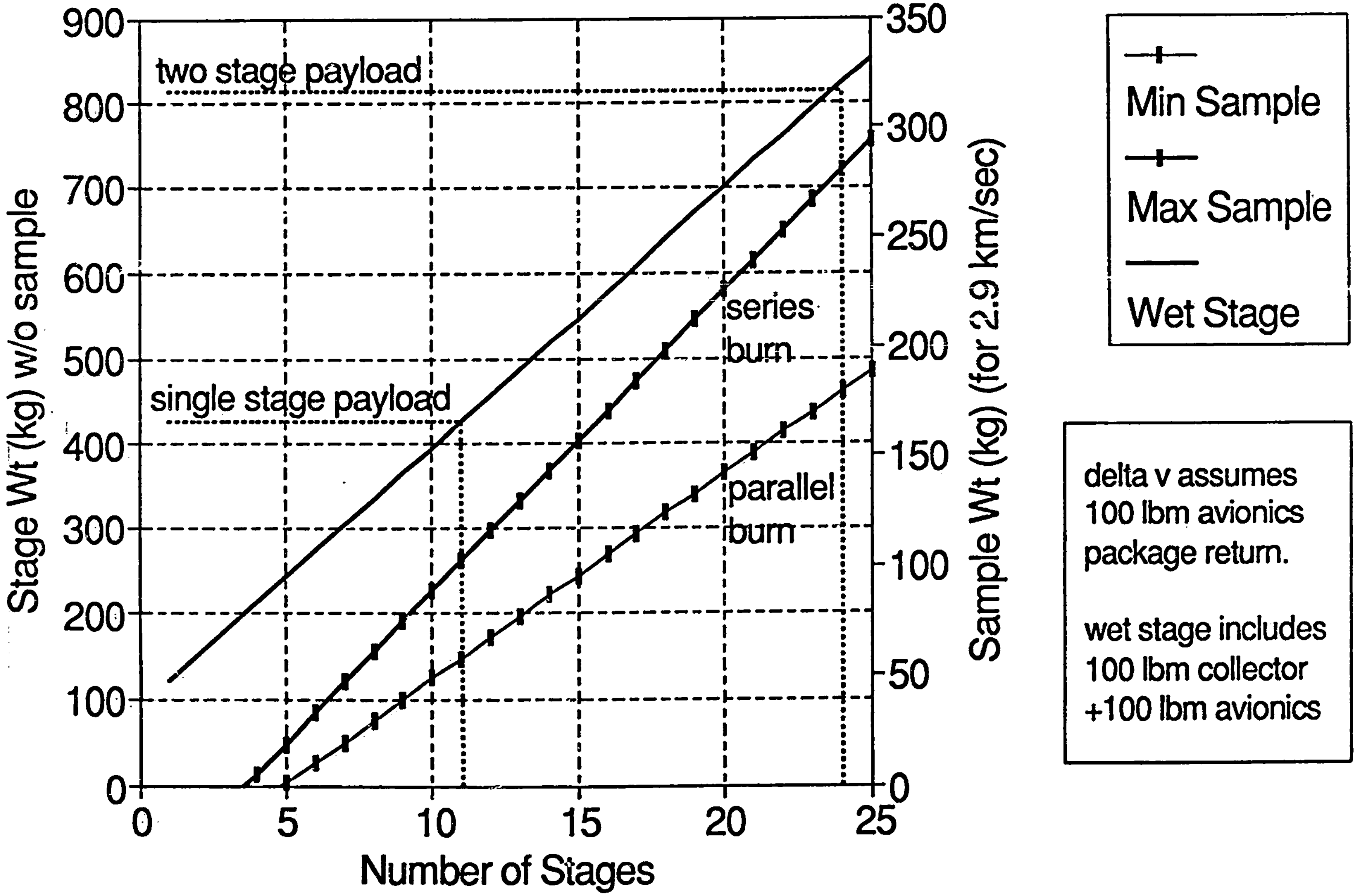


Ascent Vehicle For Sample Return Can Be Built Using Clustered ALAS Stages



53.

Lunar Sample Return Mission



54.

High Performance Lunar Lander Can Be Made By 1996

- Program Elements Being Worked to Extend Life and Convert to N_2O_4/MMH
- Performance Capabilities Will Enable Significant Payloads to be Deployed/Retrieved
- Avionics and Other Stage Requirements Need to be Quantified ASAP

Near Term Start Required to Ensure Success

TRW Federal Systems
Division
Space & Technology Group

TRW'S
VARIABLE THRUST ENGINE
(VTE)

DESIGN/PERFORMANCE/HERITAGE

Dave Younkin

02 July 1991

2

TRW Federal Systems Division
Space & Technology Group

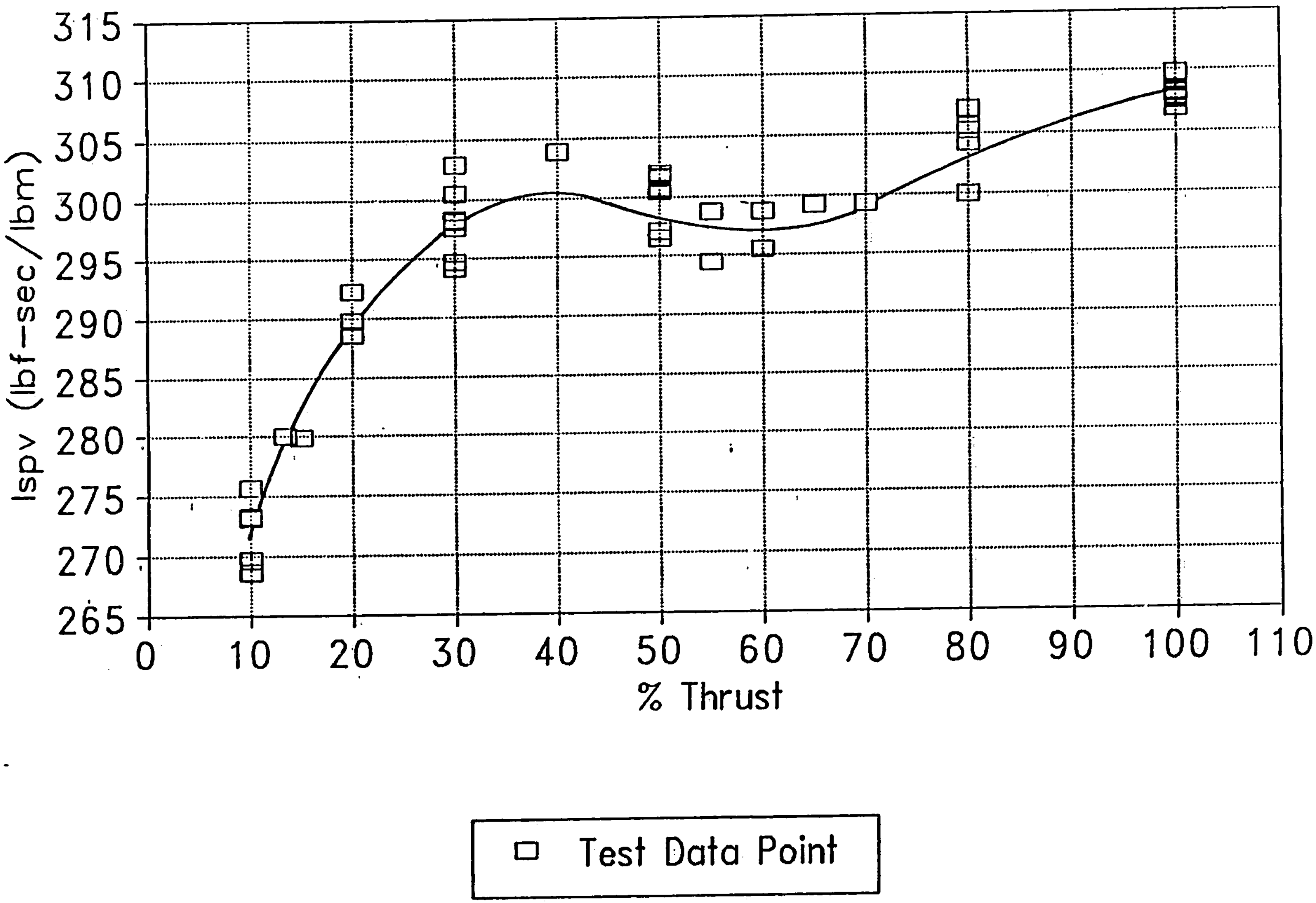
VTE DESIGN FEATURES

TRW

ENGINE TYPE	-	125:1 AREA RATIO - RADIATION COOLED THROTTLEABLE BIPROPELLANT ENGINE
PROPELLANTS	-	MONOMETHYLHYDRAZINE (MMH)/NITROGEN TETROXIDE (N204) MON-3
THRUST	-	10:1 THROTTLEABLE FROM 13 lbf to 130 lbf
THROTTLE RE-SPONSE RATE	-	25.4 lbf/SECOND
MIXTURE RATIO	-	1.64
OPERATING LIFE	-	4.68 X 10^6 lbf - SECONDS (EQUIVALENT TO 8 HOURS AT MAXIMUM THRUST)
CHAMBER/NOZZLE MATERIAL	-	COLUMBIUM WITH R512E DISILICIDE COATING
WEIGHT	-	17 LBS

TRW Federal Systems Division
Space & Technology Group

VTE - VACUUM ISP PERFORMANCE DVT ENGINES



4

TRW Federal Systems Division
Space & Technology Group

VTE HERITAGE - DESIGN BASED ON SIMILAR TRW FLIGHT ENGINES

TRW

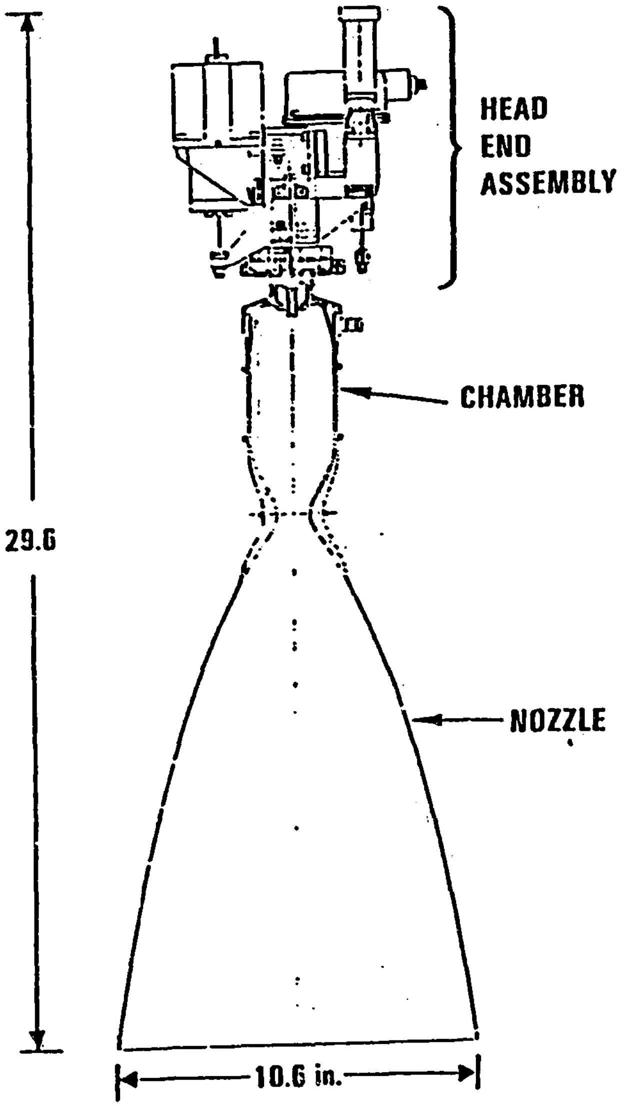
ENGINE	PROGRAM	ACHIEVEMENTS
30-150 lbf VARIABLE THRUST	SURVEYOR JPL	• DEVELOPED, QUALIFIED AND DELIVERED 16 ENGINES
1050 - 10,500 lbf VARIABLE THRUST	LUNAR MODULE DECENT ENGINE (LMDE) GRUMMAN	• 84 ENGINES MANUFACTURED • 5 LUNAR LANDINGS • 1 SPACE RESCUE
88 lbf FIXED THRUST COLUMBIAN RADIATION COOLED	MULTI-MISSION BIPROPELLANT ENGINE (MMBPS) CLASSIFIED	• FLIGHT QUALIFIED • 25,000 SECONDS LIFE DEMONSTRATION
8200 - 3242 lbf VARIABLE THRUST ATTITUDE CONTROL	SENTRY MMC/ARMY	• FLIGHT WEIGHT DEMONSTRATIONS • ADVANCED THRUST MODULATION • HIGH THRUST-WEIGHT HIGH PERFORMANCE

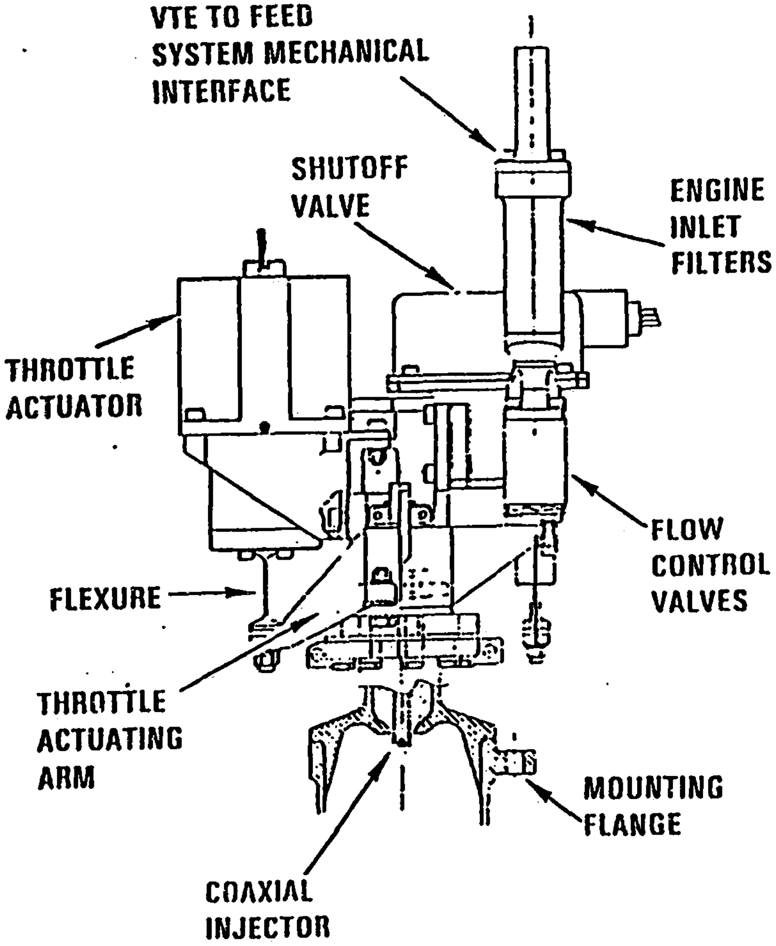
VTE DEVELOPMENT STATUS

	STATUS	TYPE OF HARDWARE	TEST PROGRAM
DEVELOPMENT PHASE	COMPLETED	WORKHORSE	PERFORMANCE AND THROTTLING CHARACTERIZATION
DESIGN VERIFICATION TEST (DVT) PHASE	STARTED - NOT COMPLETED	PROTOTYPE	DOME THERMAL PROBLEM ENCOUNTERED DURING INITIAL TESTING. THERMAL PROBLEM RESOLVED. TEST PROGRAM TERMINATED DUE TO OMV CANCELLATION.
QUALIFICATION PHASE	PIECE PARTS FABRICATED - TEST PROGRAM NOT STARTED	FLIGHT	VERIFICATION OF ENGINE PERFORMANCE AND LIFE AFTER SUCCESSFUL COMPLETION OF DVT

TRW Federal Systems Division
Space & Technology Group

VARIABLE THRUST ENGINE





7

LANDER PROGRAMMATICS

8.

Common Lunar Lander Workshop
Programmatics Agenda

Ron Kahl	NIO	Management
Brett Drake	LMEPO	Cultural Change SEI Early Milestones
Gail Boyes	Procurement	Acq. Strategy & SME
Alan Delamere	Ball	Discoverer
Otto Steinbruner	GD	
Phil Dempsey	LMEPO	Lander Schedules
Lisa Guerra/Phil Dempsey		Mercury Analog
Kelley Cyr	LMEPO	Cost Analysis

Common Lunar Lander Workshop

Programmatics Summary

- Programs like this e.g. surveyor cost ~ 3/4 billion and take 6-8 years. Surveyor driven by Centaur technology

- These parameters may be unacceptable for CLL

- To reduce these factors will require rethinking/redefining typical NASA programmatic approaches

- These kinds of changes have appeared before, e.g. Mercury, Lunar Observer, Solar Mesospheric Exploration and resulted in successful programs. However there is some risk, e.g. Ranger

- Many ideas were discussed for how to improve:
  - Short program
  - Small staff
  - Define requirements early and stick to them
  - Use contractor reporting
  - Concurrent engineering
  - Single interface with externals
  - Do not follow the traditional NASA ϕ A, B, C approach
  - Use proven technology
  - Keep it simple
  - Champion

- An intriguing concept would be to use a service contract rather than a hardware development contract

Business as Unusual

- Eliminate personnel layering - trust
- Small team univ./NASA/industry
- Led by personal champion
- Fixed funding profile
- No top level changes
- Key milestones for cancellation
- No Phase A/B/C/D
- Reward success
- Short program - 2 years

Implementation

- AO competition - teams
- Select IO missions - priority
- Fund detailed proposals - first two
- Select better for full funding
- Check progress v. $
- Cancel if over-run
- Reward with follow-on or cash
- Fund more competitive starts

PROGRAMMATICS

Presentation

July 2, 1991

Ron Kahl

13.

PROGRAMMATIC GOALS

- Five year schedule from approval to launch of a Lander and its Payload
- Accomplished within Cost and Schedule
- Inexpensive Payload Delivery System
- Accommodate a wide variety of Customers or Users
- Inexpensive Payload Integration costs
- Affordable User Payload Operations

STRAWMAN PROGRAMMATIC ELEMENT OPTIONS

	Contracted	Government	Commercial	Users
Launch Vehicle		X	X	
Lander	X	X	X	
Payload				X
Payload Integration	X	X	X	X
Payload Operations	X	X	X	X

STRAWMAN PROGRAMMATIC ELEMENT OPTIONS

LAUNCH VEHICLE

- Options to be examined include Government or Commercial

LANDER

- Options to be considered include Contracted, Government, Commercial and combinations

PAYLOAD

- The only option here is USER, although the USERS will include the Government, Contractors and Commercial as well

PAYLOAD INTEGRATION

- Options to be considered include Contracted, Government, Commercial or Users

PAYLOAD OPERATIONS

- Options to be considered include Contracted, Government, Commercial or Users

CHALLENGES

- To Accomplish Programmatic Goals requires strong commitments by NASA as well as any participant in Program
- New NASA Management and Organizational Approaches must be developed as part of this Program
- Innovative Acquisition Strategies must also be developed as part of this Program
- The Relationship between Service Provider and Users must be different from historical

WE NEED YOUR HELP

- Identification of NASA Impediments and Recommended Solutions in Management, Organizational, Acquisition, and Relationships
- Identification of Same for Industry and/or Academia

LANDER PROGRAMMATICS PLAN

- Develop approaches for Organizationally Isolating from Outside influences as much as possible

- Investigate Organizational Concepts which Streamline Management and Minimize Involvement
  - DOD approaches to be considered

- Develop strategy to assure that Cost Estimates matches Budget Availability at Program start
  - Early agreement on Requirements, Concept and Costs
  - Requirements frozen (except to relax)

- Examine alternative Acquisition Strategies for Contracted and Commercial
  - Incentives for Cost, Schedule and Accomplishment
  - Specification of Mission Performance and Interface
  - Minimal Reporting (Paperwork)

PAYLOAD INTEGRATION PROGRAMMATIC PLAN

- Investigate Organizational and Management Structure alternatives for
    - Manifesting and prioritizing payloads from multiple users such that individual user cost is minimized
    - Dealing with any interface issues between user and provider
- Examine alternative Organizational concepts which Streamline Management and provide a useful service without overburdening user or provider with excessive bureaucratic paperwork, red tape and costs

19.

LAUNCH VEHICLES

ATLAS FOR LAUNCH OF COMMON LUNAR LANDERS

JULY 2, 1991

GENERAL DYNAMICS
Space Systems Division
Commercial Launch Services

21

For additional Delta II information, contact:

Jack Kirk
McDonnell Douglas Space Systems Co.
Huntington Beach, CA

(714) 896-4664

ATLAS / CENTAUR HERITAGE - SURVEYOR MISSIONS

CENTAUR WAS DESIGNED AND DEVELOPED TO CARRY SURVEYOR SPACECRAFT FOR REMOTE LANDINGS ON THE MOON

ATLAS AND CENTAUR BOTH SUCCESSFUL ON ALL 7 SURVEYOR MISSIONS

GUIDANCE ACCURACY WAS EXCELLENT IN MEETING MISSION REQUIREMENTS

SUBSEQUENT ATLAS AND CENTAUR EVOLUTION HAVE FURTHER ENHANCED CAPABILITIES TO CARRY A COMMON ROBOTIC LUNAR LANDER

- LARGER FAIRINGS
- GREATER ACCURACY
- HEAVIER PAYLOAD CAPABILITY

ATLAS / CENTAUR RECORD FOR SURVEYOR LUNAR LANDERS

MID COURSE CORRECTION FOR 2 BURN MISSIONS (m/sec)

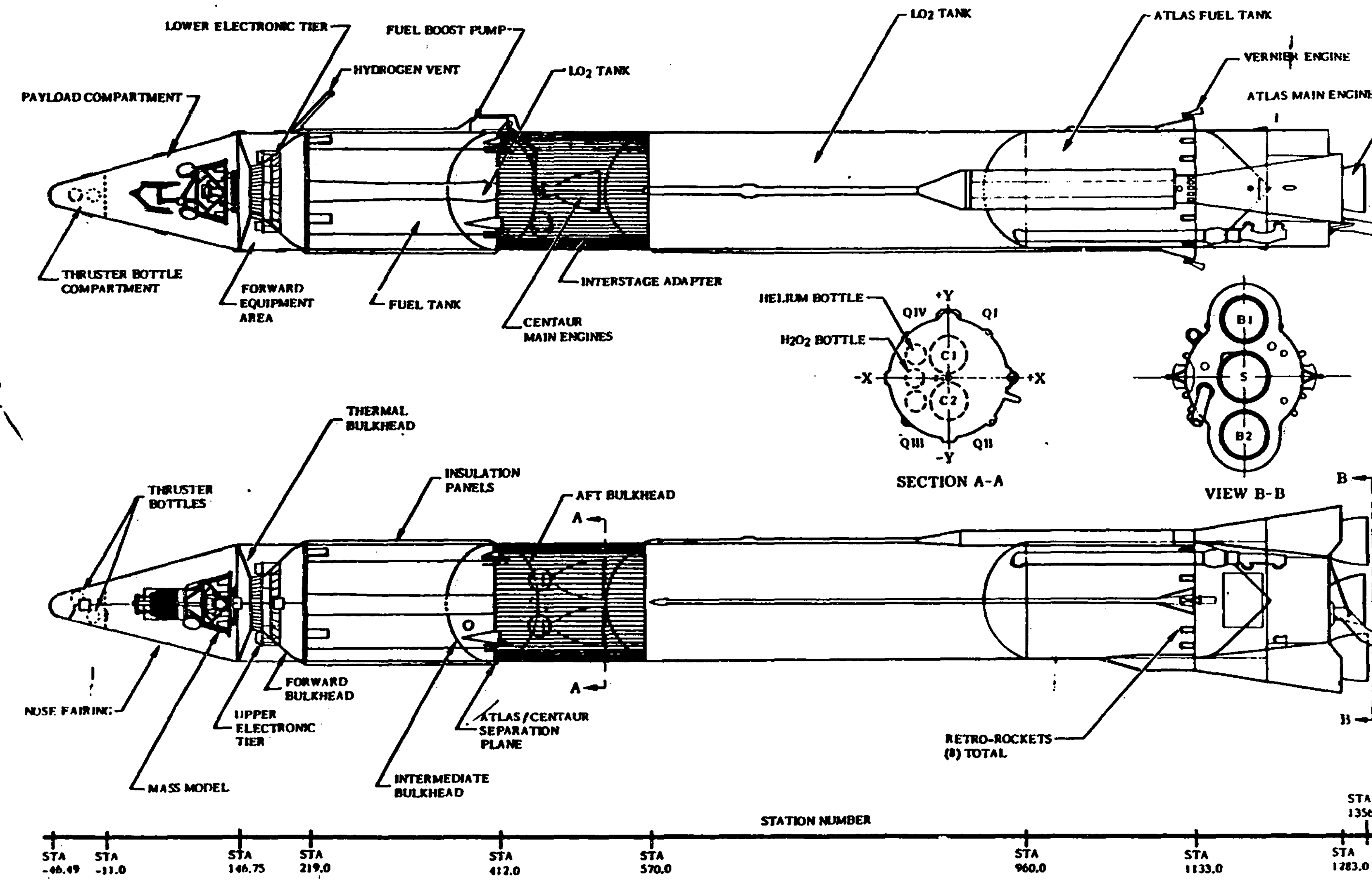
FLIGHT NUMBER	EXPECTED ACCURACY		FLIGHT RESULTS	
	DIRECTION	DIRECTION PLUS TIME OF FLIGHT	DIRECTION	DIRECTION PLUS TIME OF FLIGHT
AC-12	13.00	16.90	3.94	6.07
AC-13	11.50	18.60	0.55	1.21
AC-14	9.20	17.90	1.35	2.21
AC-15	9.60	9.80	0.33	1.21

AC-14 EXAMPLE MISSION ACCURACY (SURVEYOR 6)

PARAMETER	EXPECTED VALUE	FLIGHT RESULTS
ECCENTRICITY	.981272	.981248
INCLINATION (degrees)	29.0146	29.0043
LONG. OF ASCENDING NODE (deg)	4.2454	4.2842
C3 (km2 / sec2)	-1.32101	-1.32307
APOGEE ALTITUDE (km)	686365.12	685261.90
PERIGEE ALTITUDE (km)	169.16	168.02
PERIOD (days)	23.810	23.758

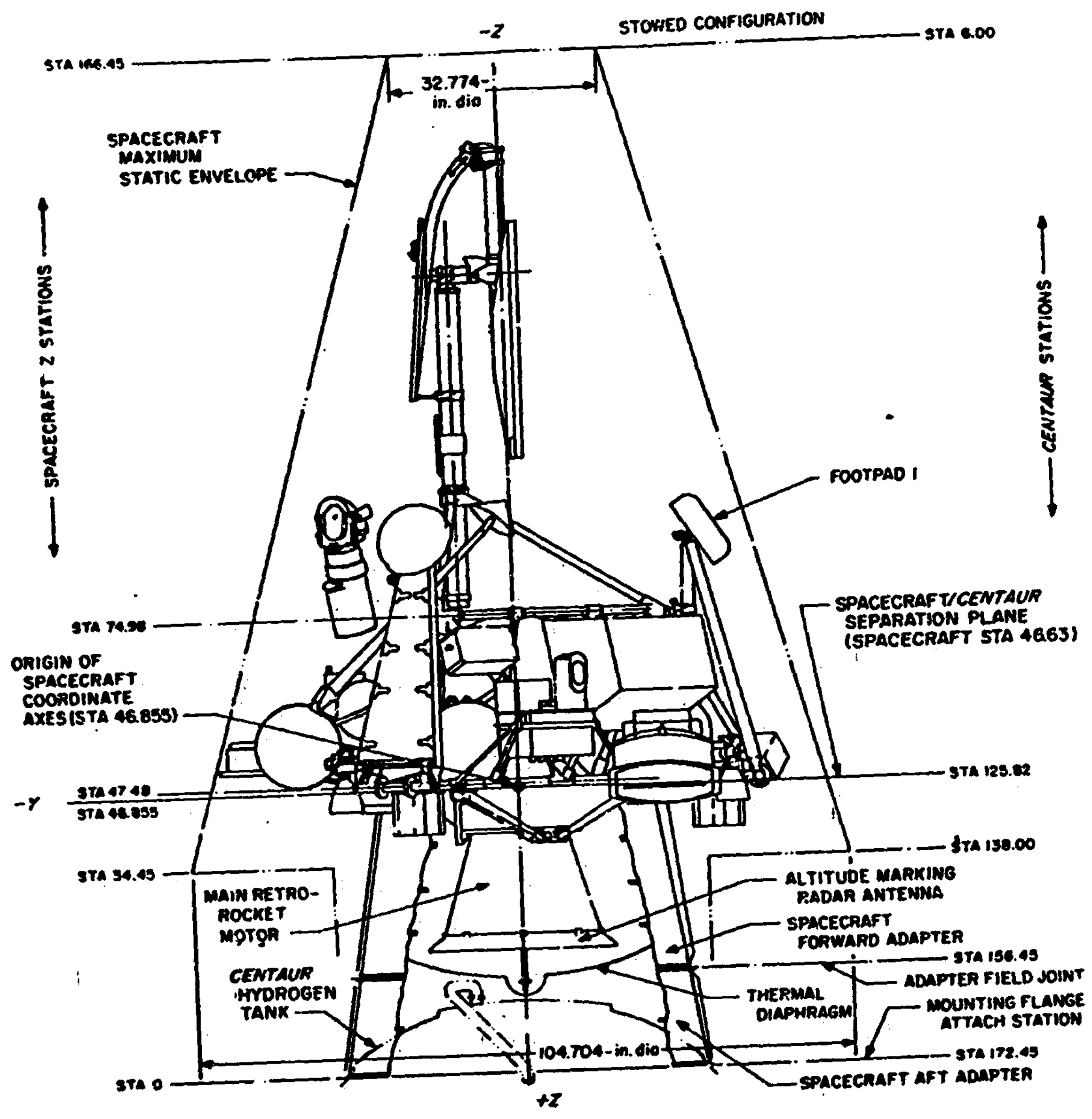
GENERAL DYNAMICS
Space Systems Division

ORIGINAL ATLAS / CENTAUR CONFIGURATION (SURVEYOR, AC-12)



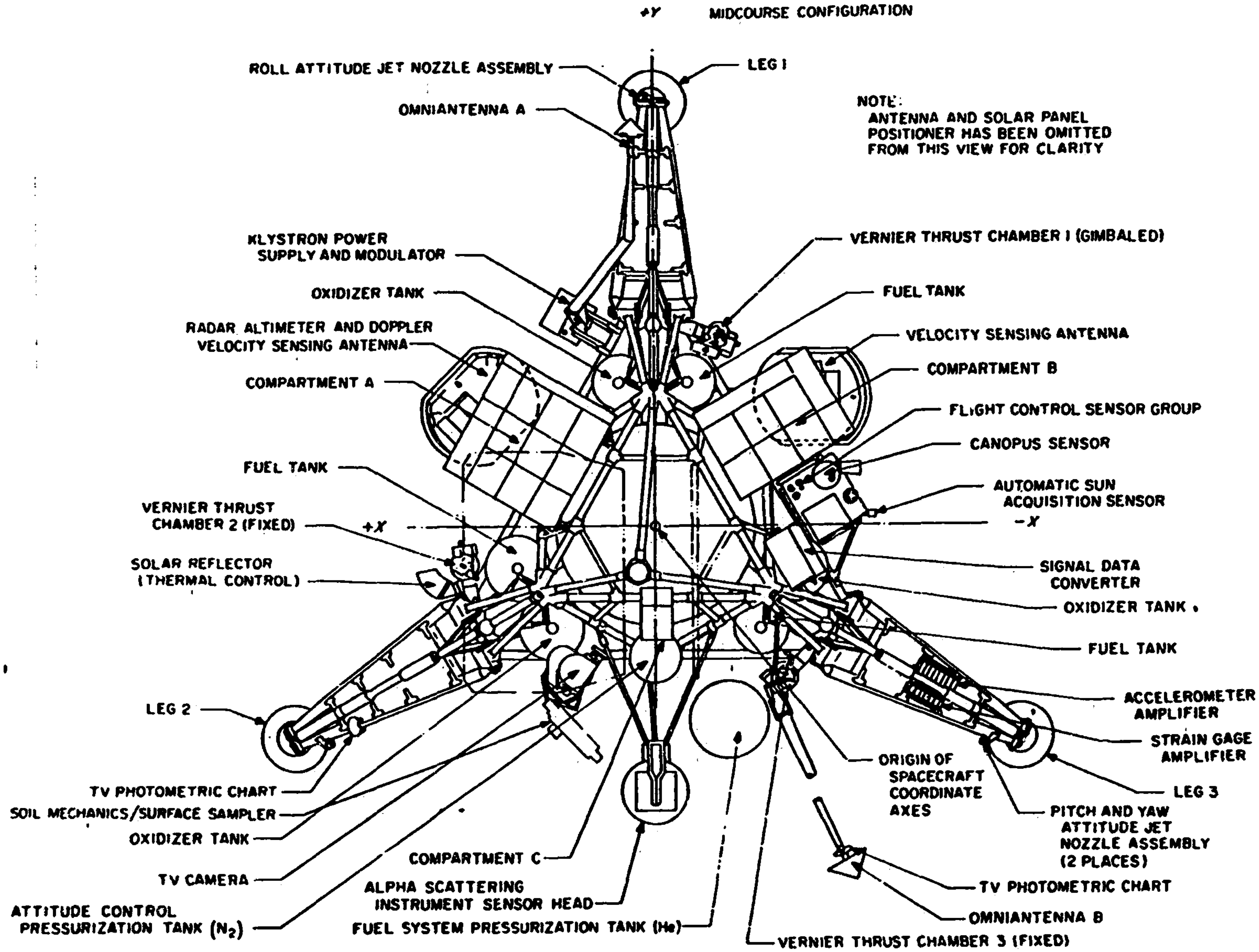
25

SURVEYOR STOWED



26

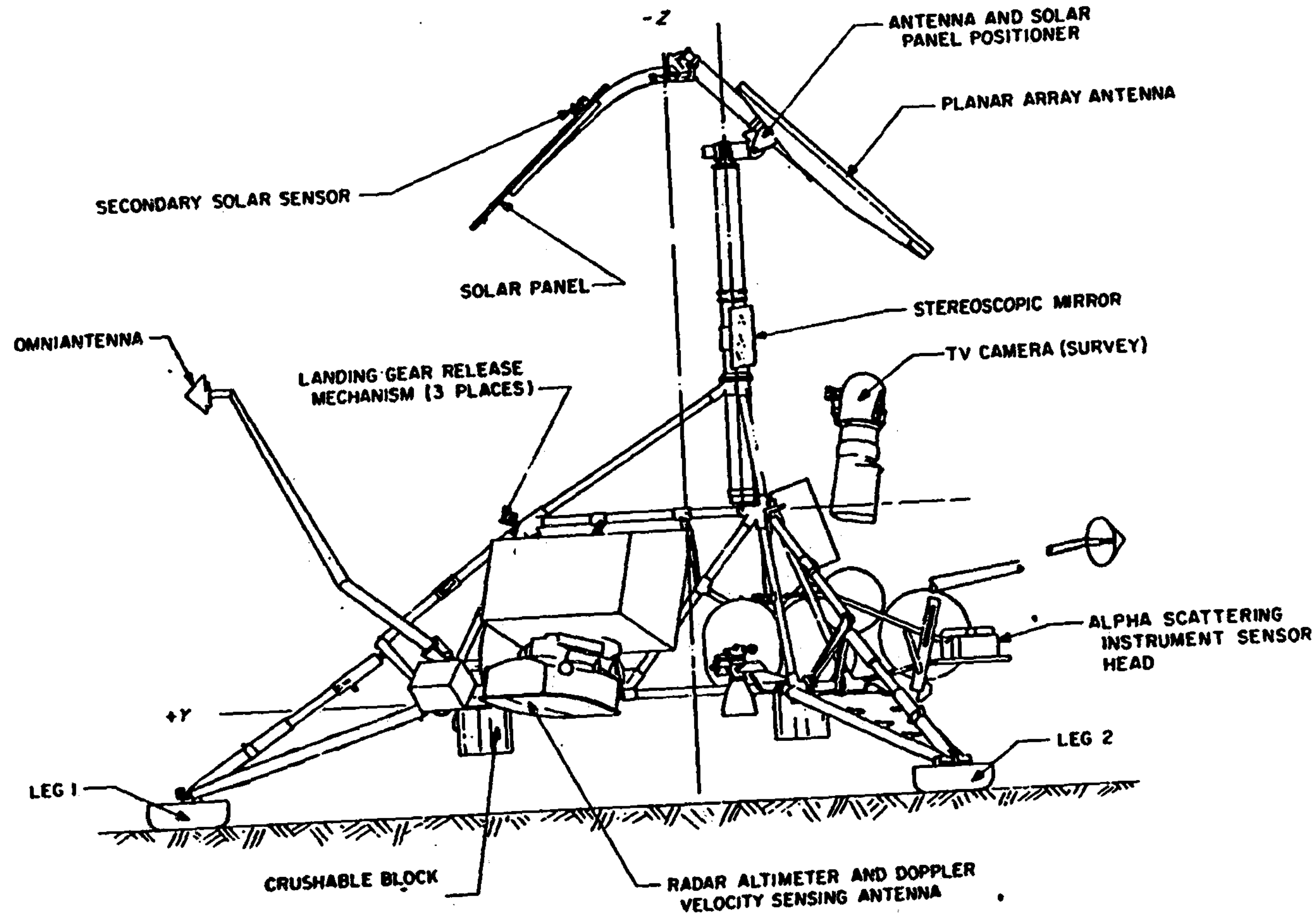
SURVEYOR MIDCOURSE



27

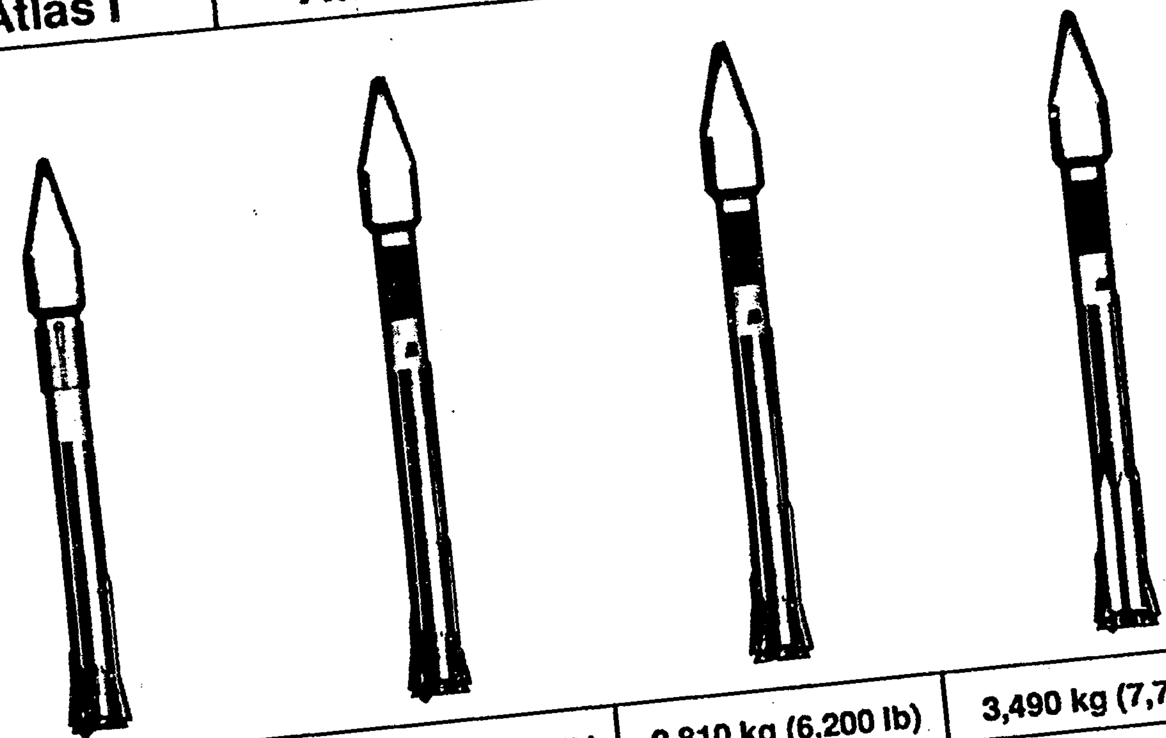
SURVEYOR POSTLANDING

POSTLANDING CONFIGURATION



24

THE COMMERCIAL ATLAS FAMILY CAPABILITIES



	Atlas I	Atlas II	Atlas IIA	Atlas IIAS
*Payload system weight to GTO	2,245 kg (4,950 lb)	2,675 kg (5,900 lb)	2,810 kg (6,200 lb)	3,490 kg (7,700 lb)
Initial launch capability	3rd qtr 1990	3rd qtr 1991	1st qtr 1992	1st qtr 1993

4.2m (14-ft) PLF shown [3.3m (11-ft) PLF optional]

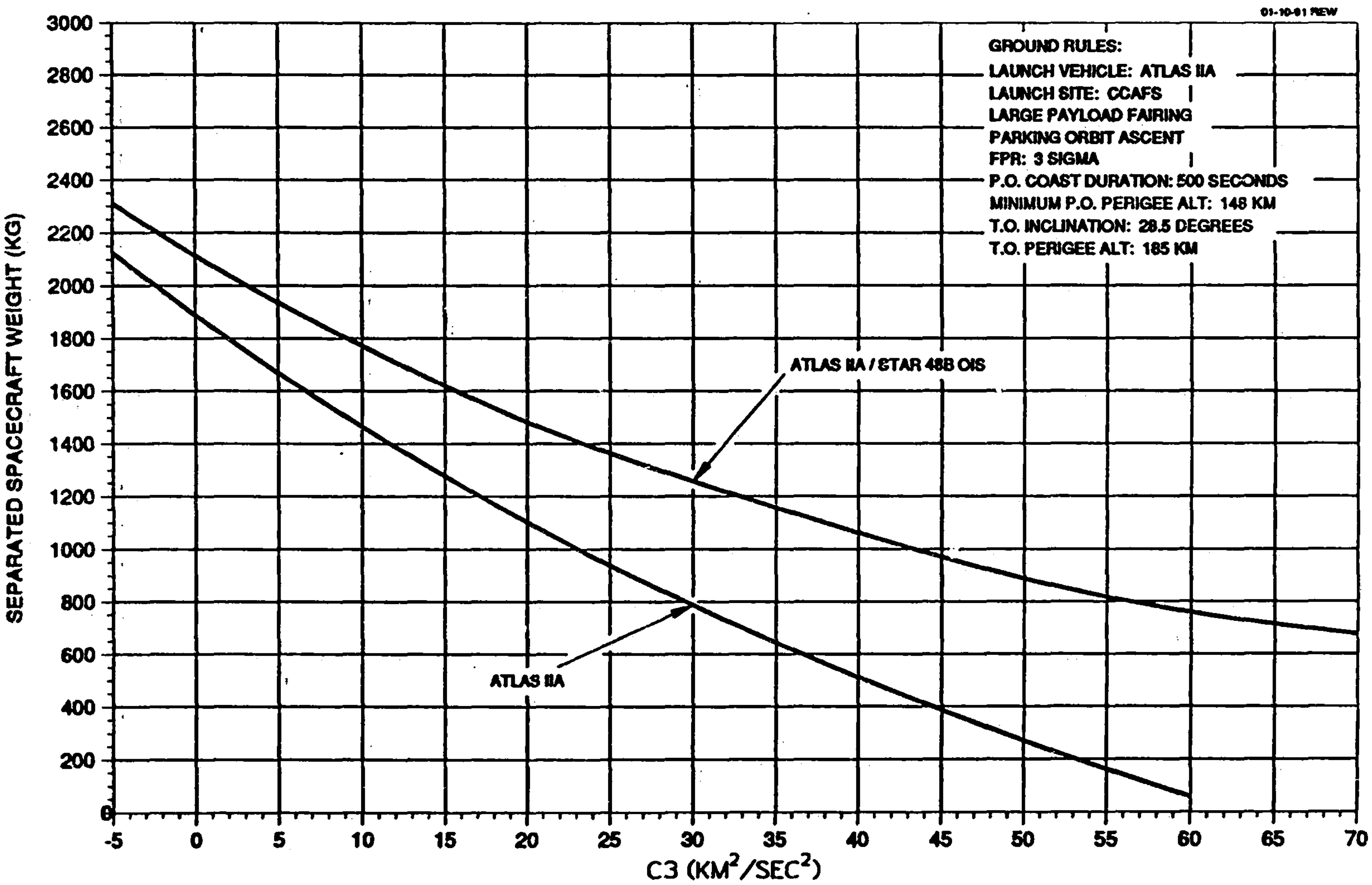
Atlas fits the near-term market

*Performance shown here is payload system weight, which includes spacecraft, payload adapter, and mission-peculiar hardware to a 28.5 degree orbit.

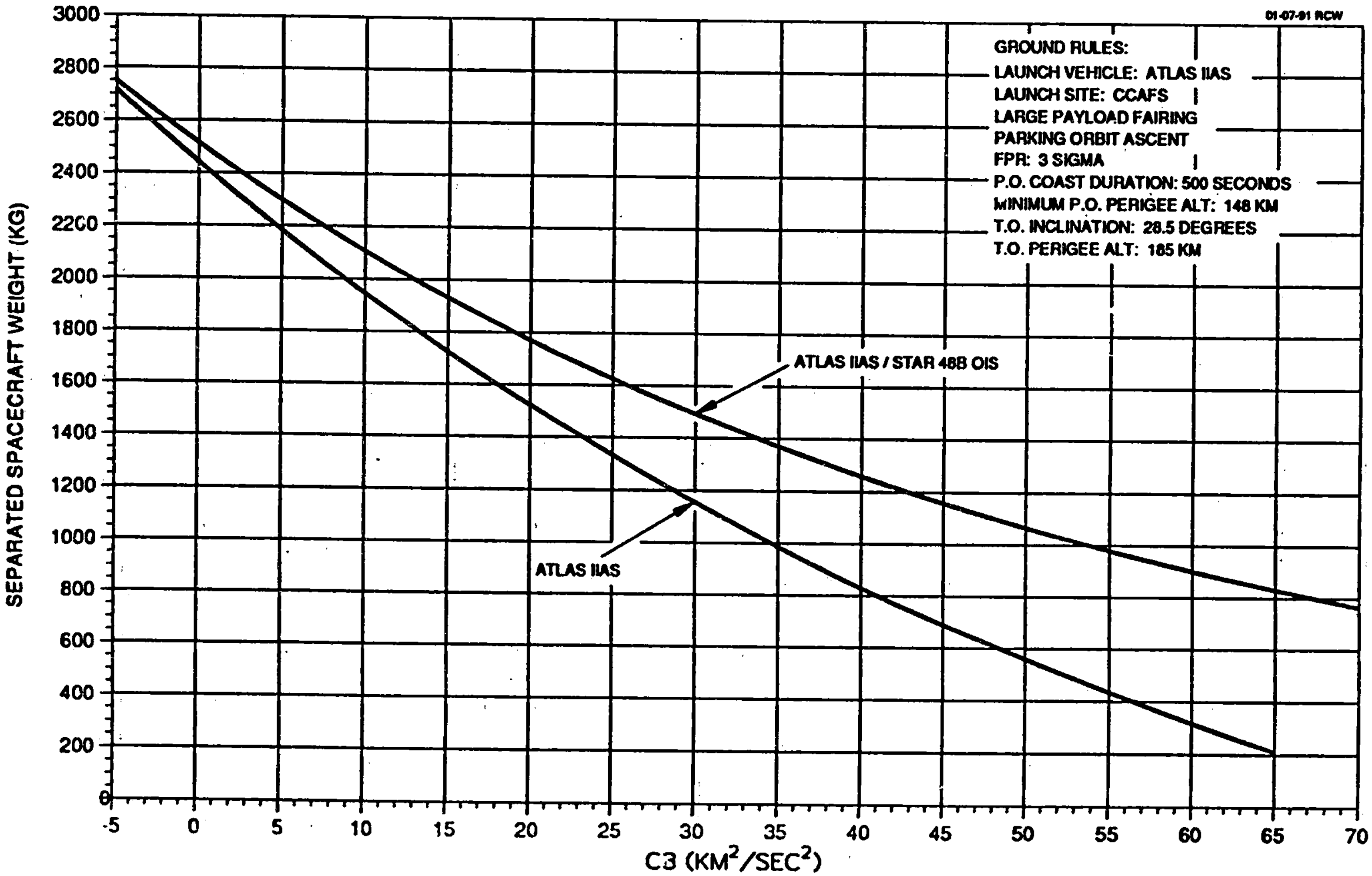
m-GSV91-2694

25

ATLAS IIA EARTH ESCAPE PERFORMANCE

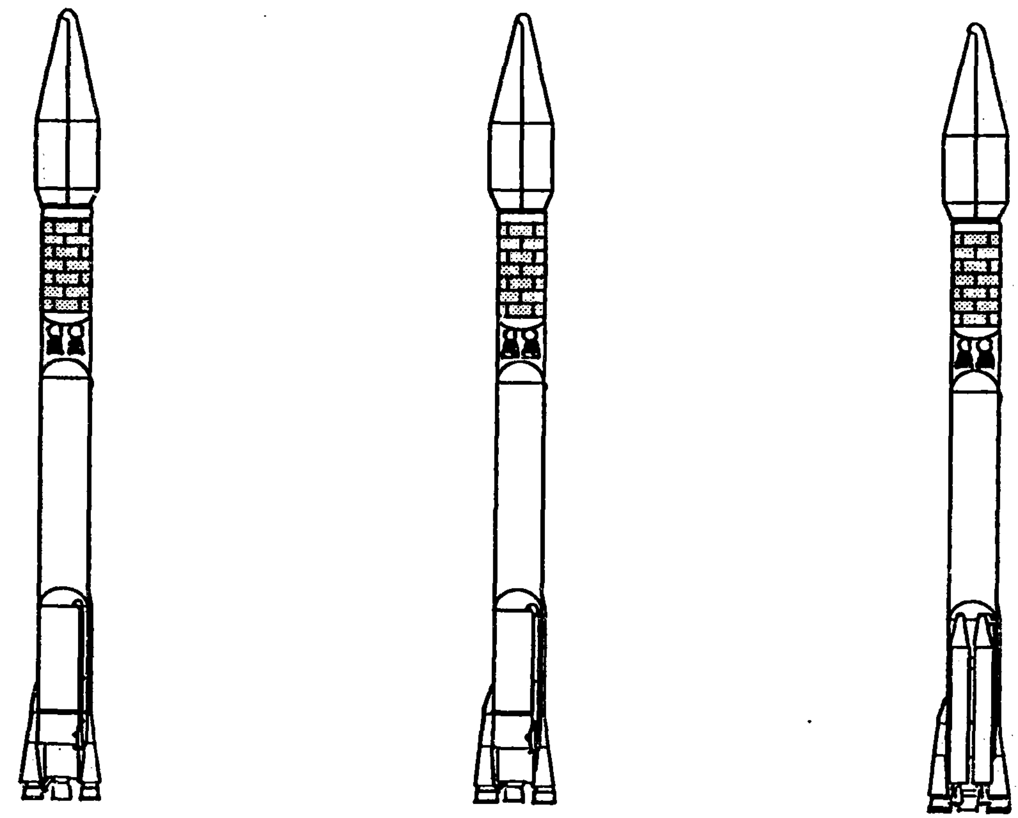


ATLAS IIAS EARTH ESCAPE PERFORMANCE



PERFORMANCE SUMMARY
LUNAR OBSERVER MISSION

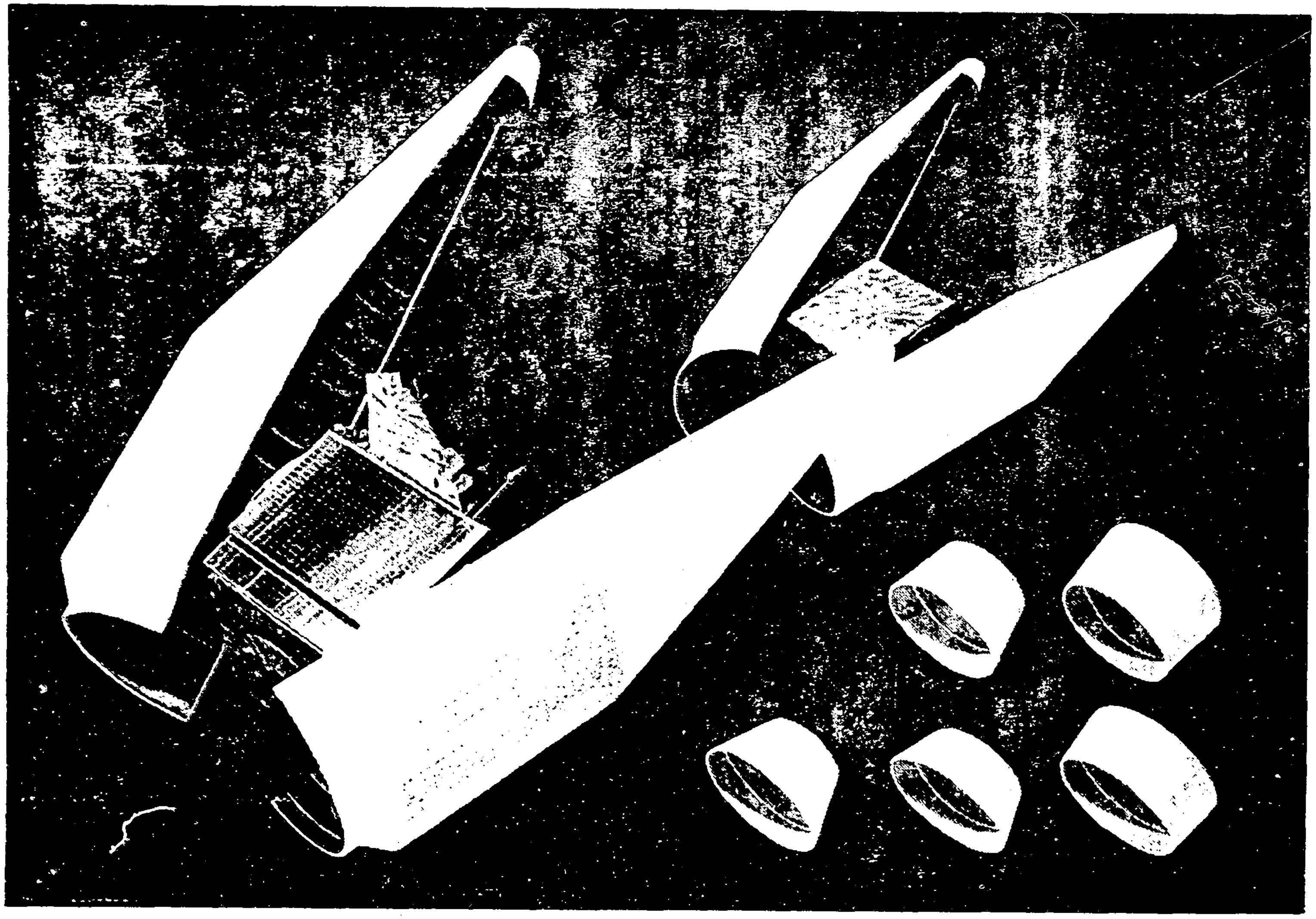
32



LAUNCH VEHICLE	Atlas II	Atlas IIA	Atlas IIAS
PAYLOAD SYSTEMS WEIGHT CAPABILITY	1851 kg	2044 kg	2593 kg

GENERAL DYNAMICS
Commercial Launch Services

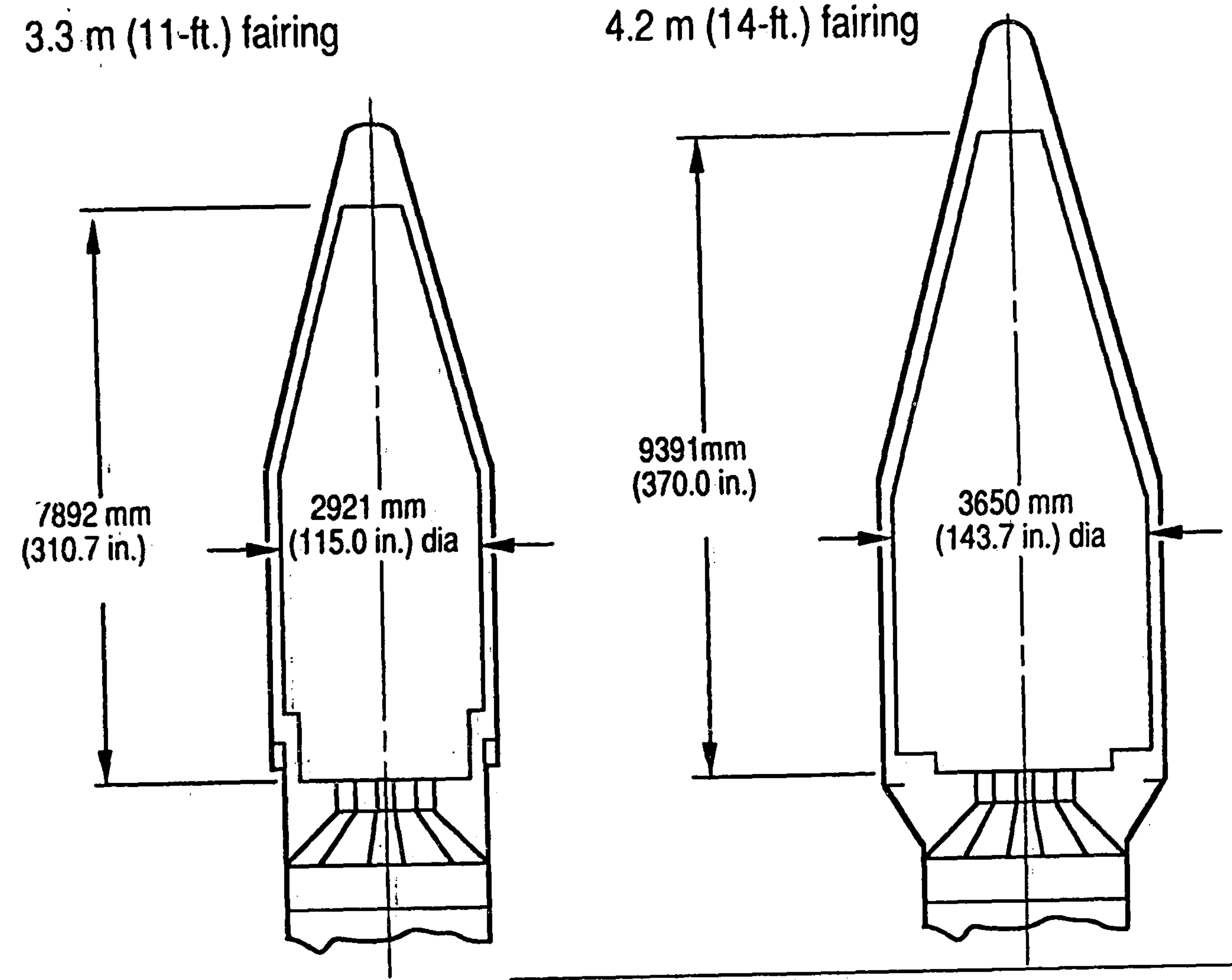
ATLAS FAIRINGS AND ADAPTERS



Atlas accommodates a wide variety of spacecraft interfaces

GSV90-2994

PAYLOAD FAIRING OPTIONS

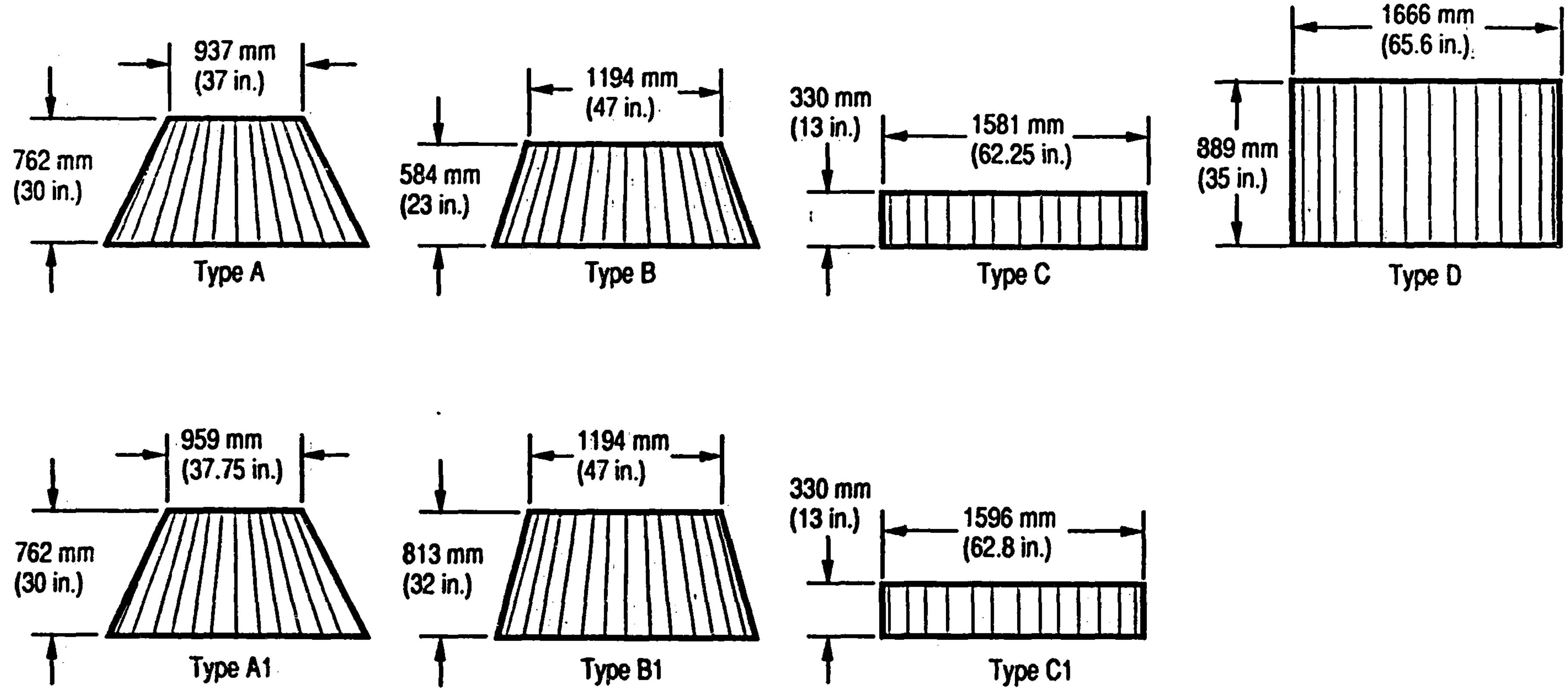


3-1

Fairing envelopes accommodate most spacecraft

GSV90-2995

SPACECRAFT ADAPTERS AND SPACERS

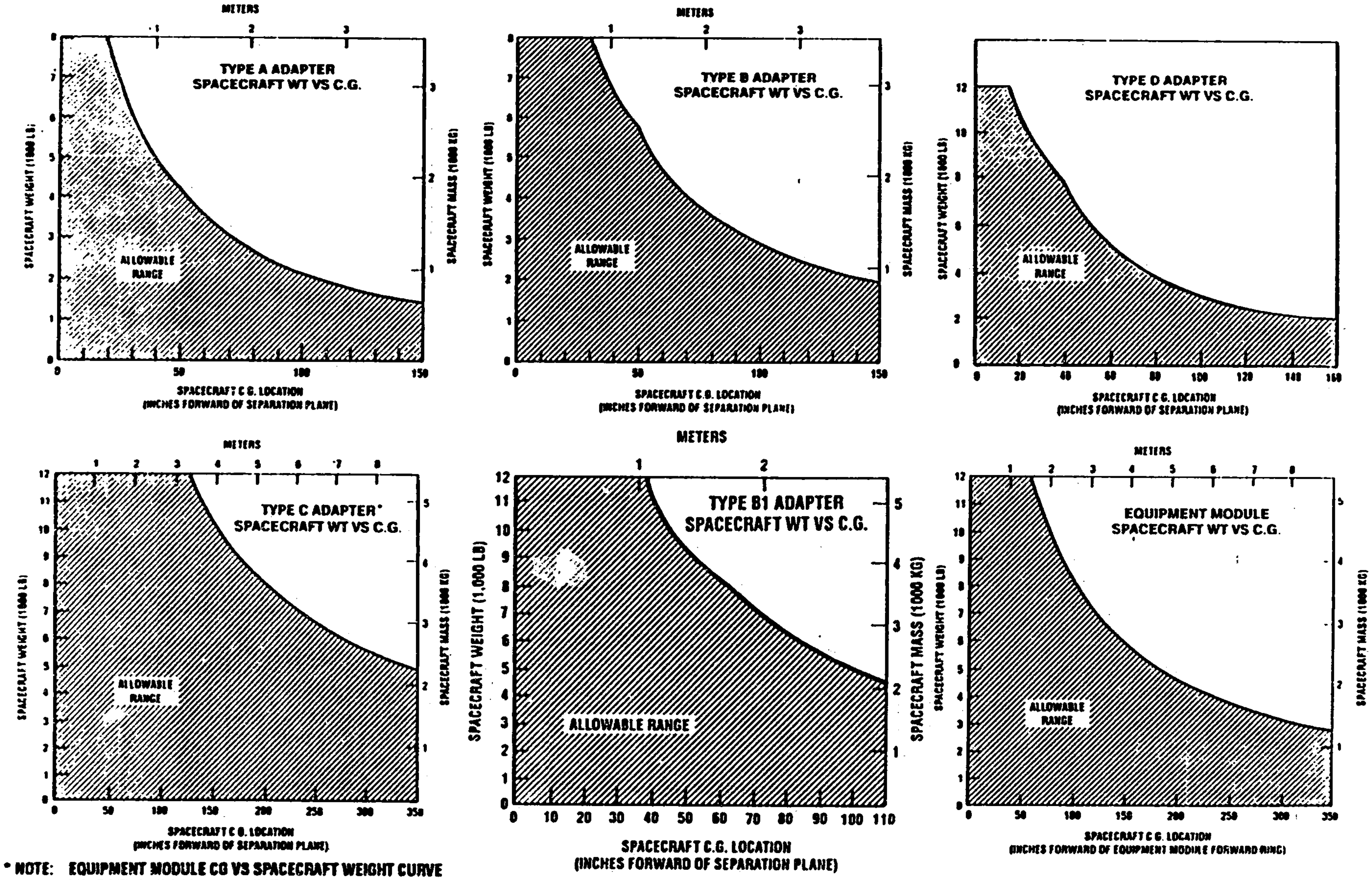


35

Atlas interfaces are compatible with most spacecraft

GSV90-2996

SPACECRAFT ADAPTER AND EQUIPMENT MODULE STRUCTURAL CAPABILITY



* NOTE: EQUIPMENT MODULE CG VS SPACECRAFT WEIGHT CURVE LIMITS THE PAYLOAD CAPABILITY OF THIS ADAPTER

CONTACT GENERAL DYNAMICS IF SPACECRAFT DESIGN EXCEEDS EQUIPMENT MODULE LIMITS

GSV90-3351A

SPACECRAFT DESIGN LOAD FACTORS

Load Condition	Direction	Steady-state (g)	Dynamic (g)
Launch	Axial Lateral	1.2 –	±1.5 (±1.8 IIAS) ±1.0 (±2.0 IIAS)
Flight winds	Axial Lateral	2.2 0.4	±0.3 ±1.2
BECO (max axial)	Axial Lateral	5.5 (5.2 IIAS) –	±0.5 ±0.5
BECO/BPJ (max lateral)	Axial Lateral	2.5–1.0 –	±1.0 ±2.0
SECO	Axial Lateral	2.0–0.0 –	±0.4 ±0.3
MECO	Axial Axial Lateral	4.0–0.0 0.0 –	±0.5 ±2.0 ±0.5

- Sign convention
  - Longitudinal axis
    - \+ (positive) = tension
    - − (negative) = compression

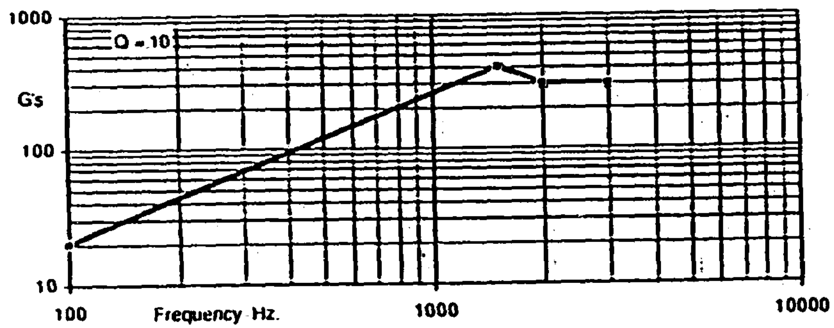
Lateral axis (pitch and yaw axis) ± May act in either direction

- Lateral and longitudinal loading may act simultaneously during any flight event
- Loading is induced through the CG of the satellite vehicle

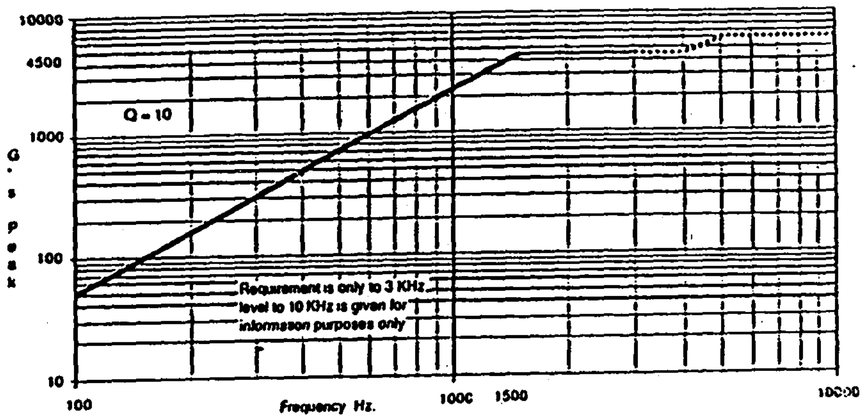
GSV90-3366

17

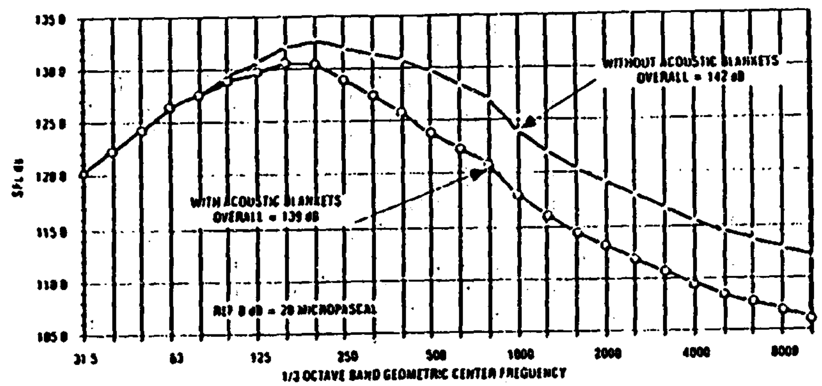
ATLAS II HIGH-FREQUENCY VIBRATION ENVIRONMENTS



Recommended shock level at payload interface due to PFJ* (maximum expected flight level)



Atlas spacecraft separation system shock level



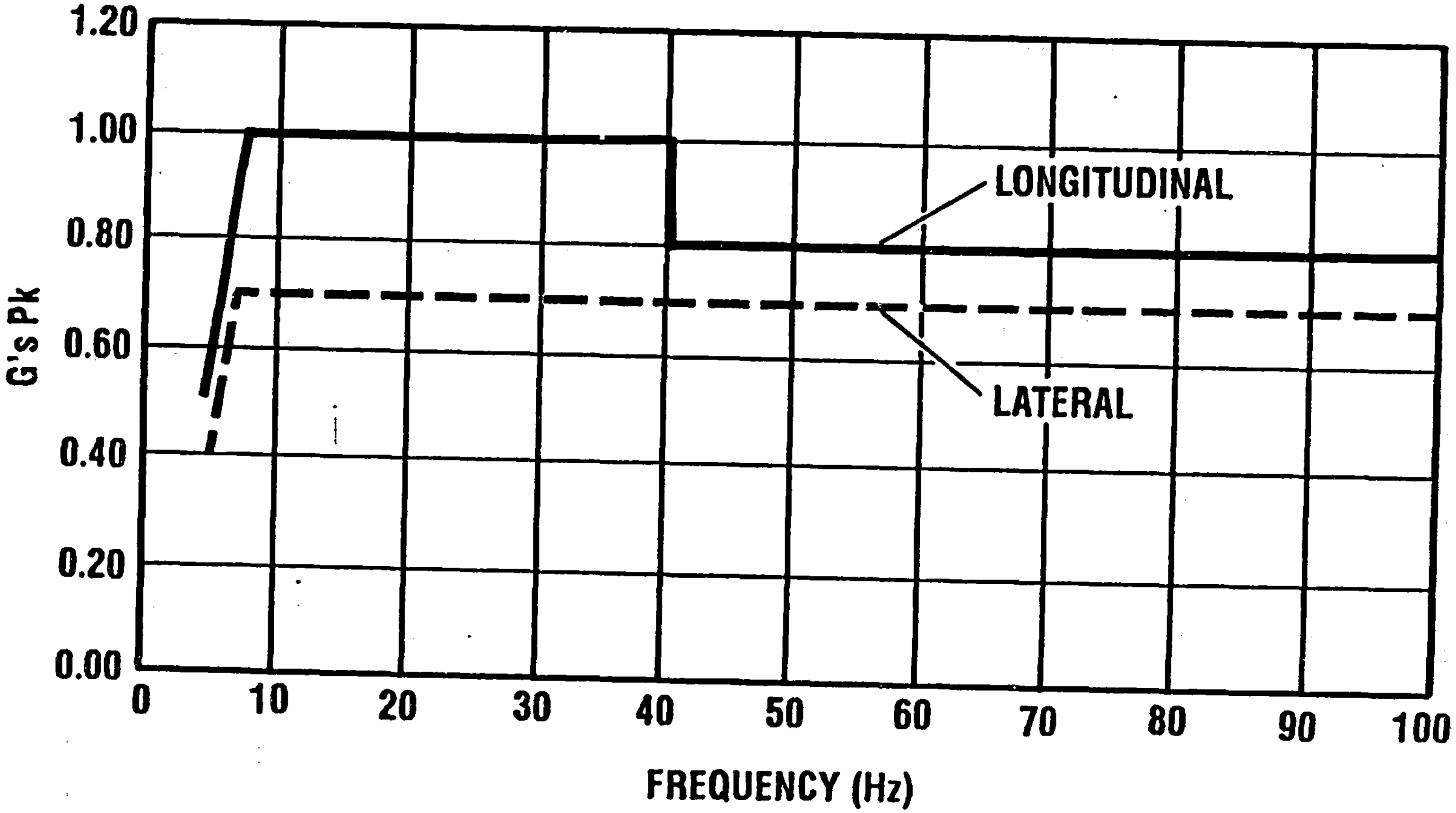
Acoustic levels for Atlas IIAS with 14-ft payload fairing

PFJ = payload fairing jettison

34

GSV90-3372A

ATLAS II LOW-FREQUENCY VIBRATION

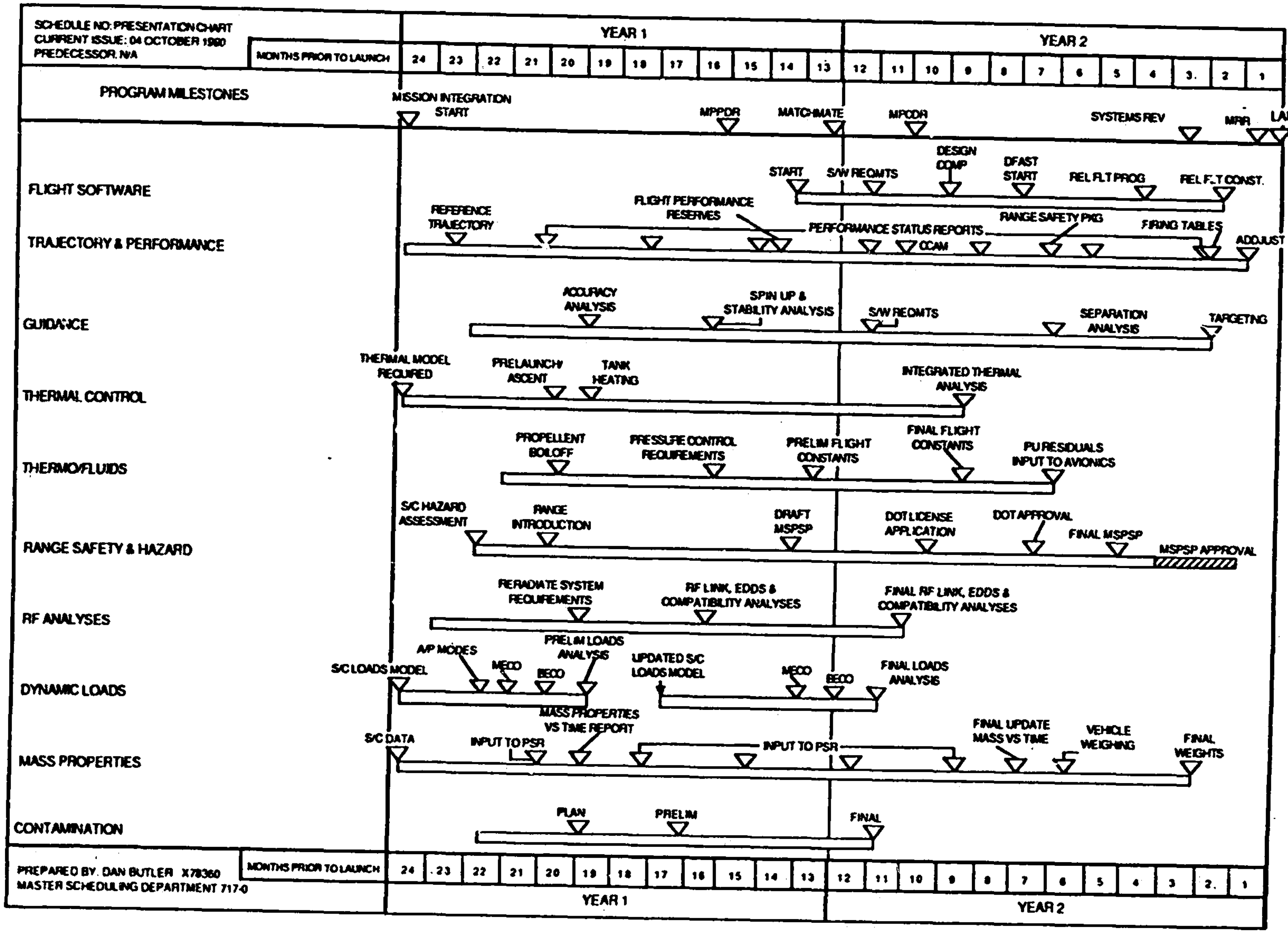


39

GSV90-3370

GENERAL DYNAMICS
Commercial Launch Services

ATLAS FAMILY TYPICAL MISSION INTEGRATION MASTER SCHEDULE

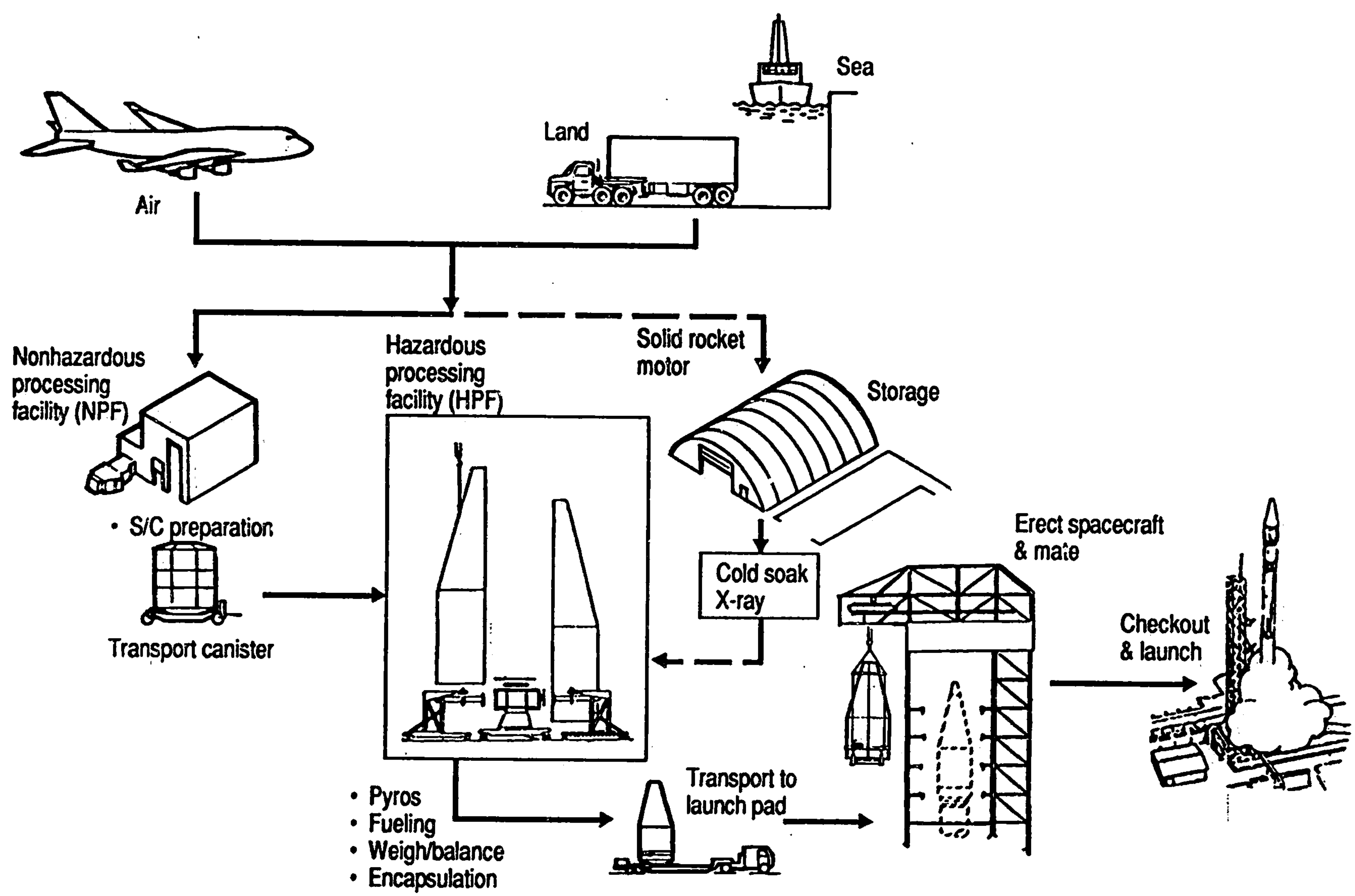


Efficient mission integration

GSV90-1927

GENERAL DYNAMICS
Commercial Launch Services

TYPICAL SPACECRAFT CAMPAIGN FLOW

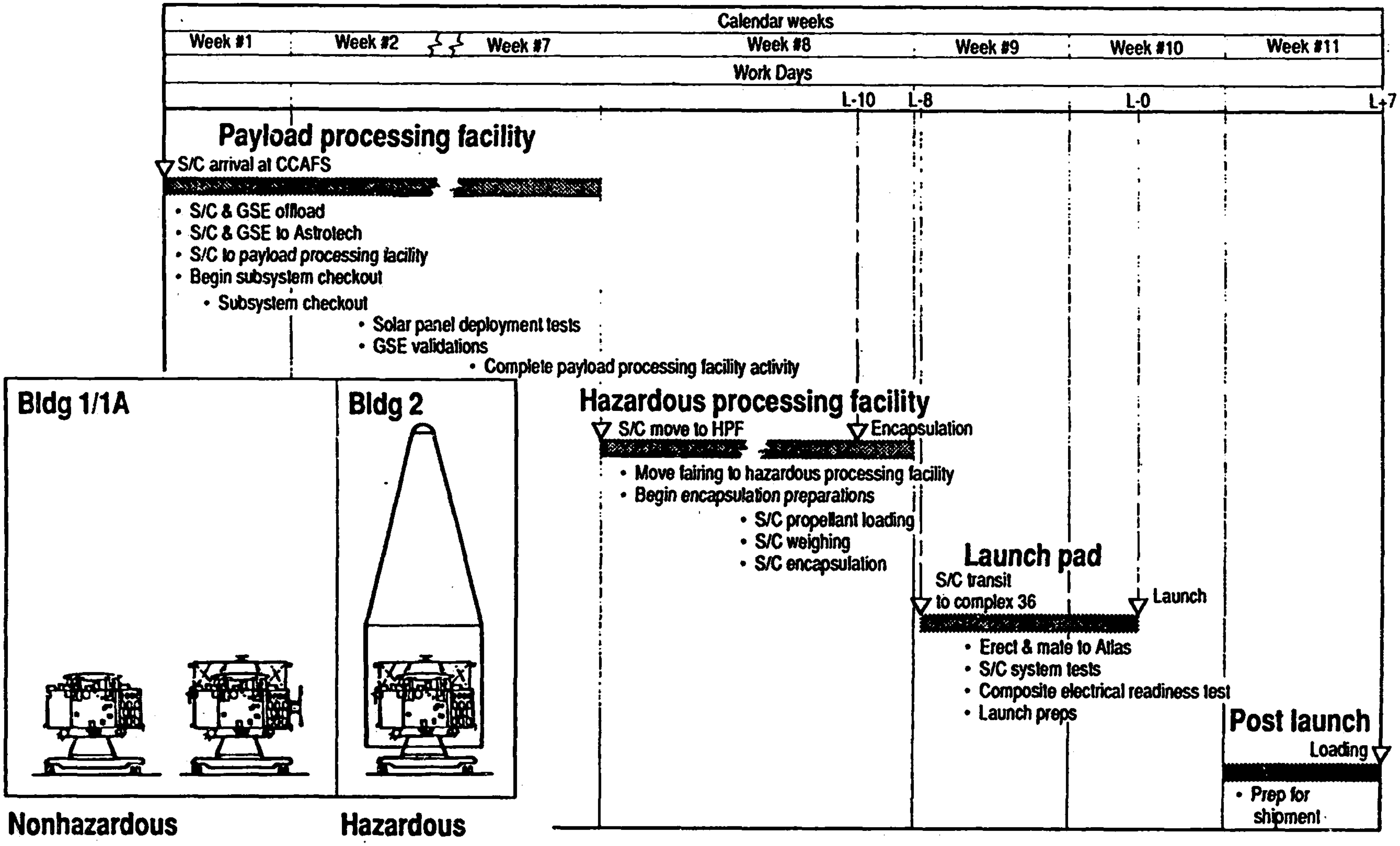


Efficient spacecraft preparation sequence

m-GSV90-2986

GENERAL DYNAMICS
Commercial Launch Services

TYPICAL SPACECRAFT LAUNCH CAMPAIGN TIMELINES



Efficient spacecraft processing

m-GSV91-1808

SUMMARY: ATLAS ATTRIBUTES FOR THE COMMON LUNAR LANDER

- RECORD OF SUCCESS ON LUNAR LANDER MISSIONS
- IDEAL RANGE OF PAYLOAD CAPABILITY
- LARGE FAIRING VOLUME AVAILABLE
- ACCURATE GUIDANCE, NAVIGATION, AND CONTROL
- COMPETITIVE COST, STRONG COMMERCIAL PROGRAM

DELTA II SUMMARY FOR THE COMMON LUNAR LANDER WORKSHOP

John M. Garvey

1-2 July 1991

Houston, Texas

McDONNELL DOUGLAS SPACE SYSTEMS CO.

CRITICAL PARAMETERS

Three-stage Delta II version (7925) for lunar missions

Payload capability for transfer orbit insertion = 1324 kg (2920 lb)
(C3 = -1.5 km2/sec2)

PAM third stage is a spinning solid rocket with a nutation control system similar to that used for the Ulysses PAM-S stage.

Standard fairing is 9.5 feet wide; 10 foot fairing is available

Dual launch pads enable closely scheduled launches

NASA already has implemented the Medium Expendable Launch Vehicle (MELV) contract which includes numerous options for Delta launches through the late 1990s.

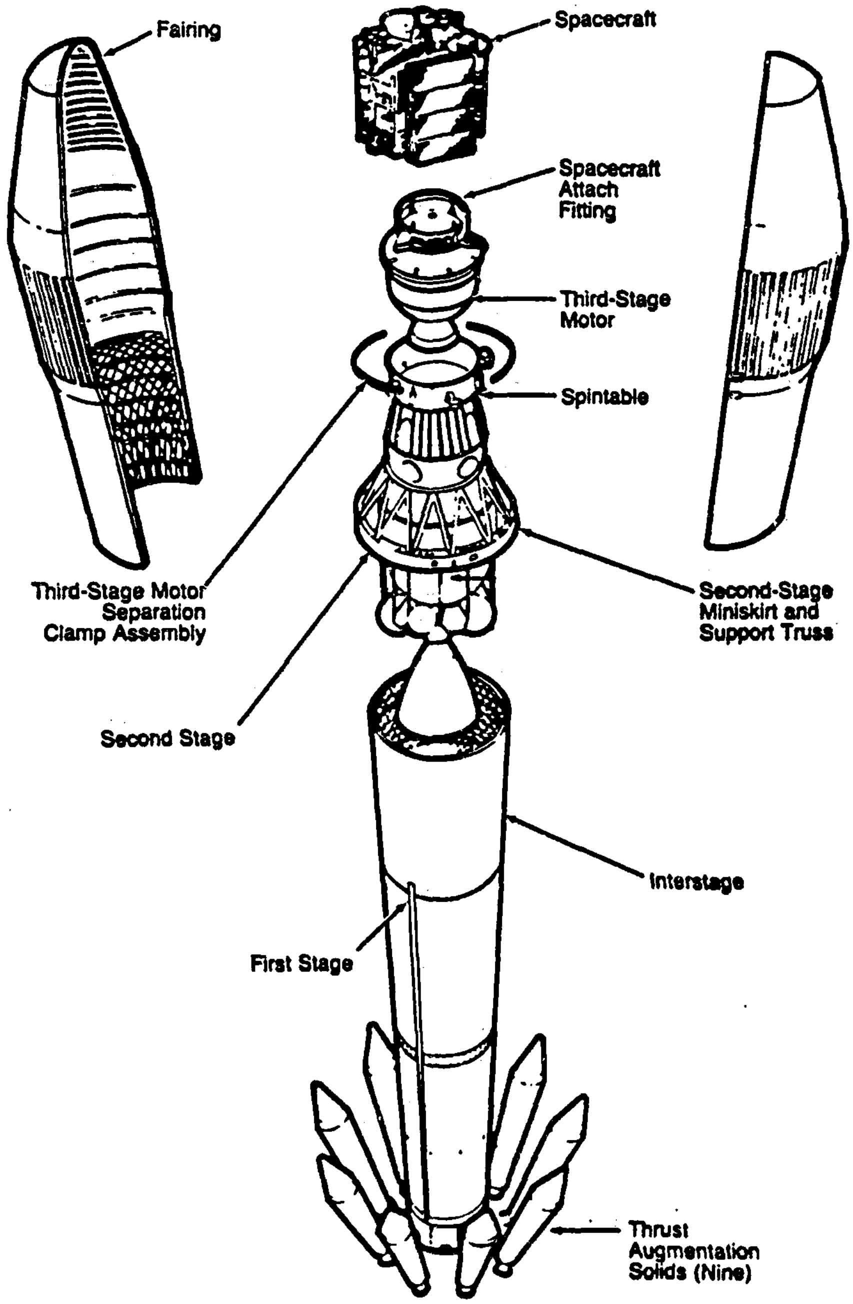


Figure 1-3. Typical Delta II Three-Stage Separation

300725

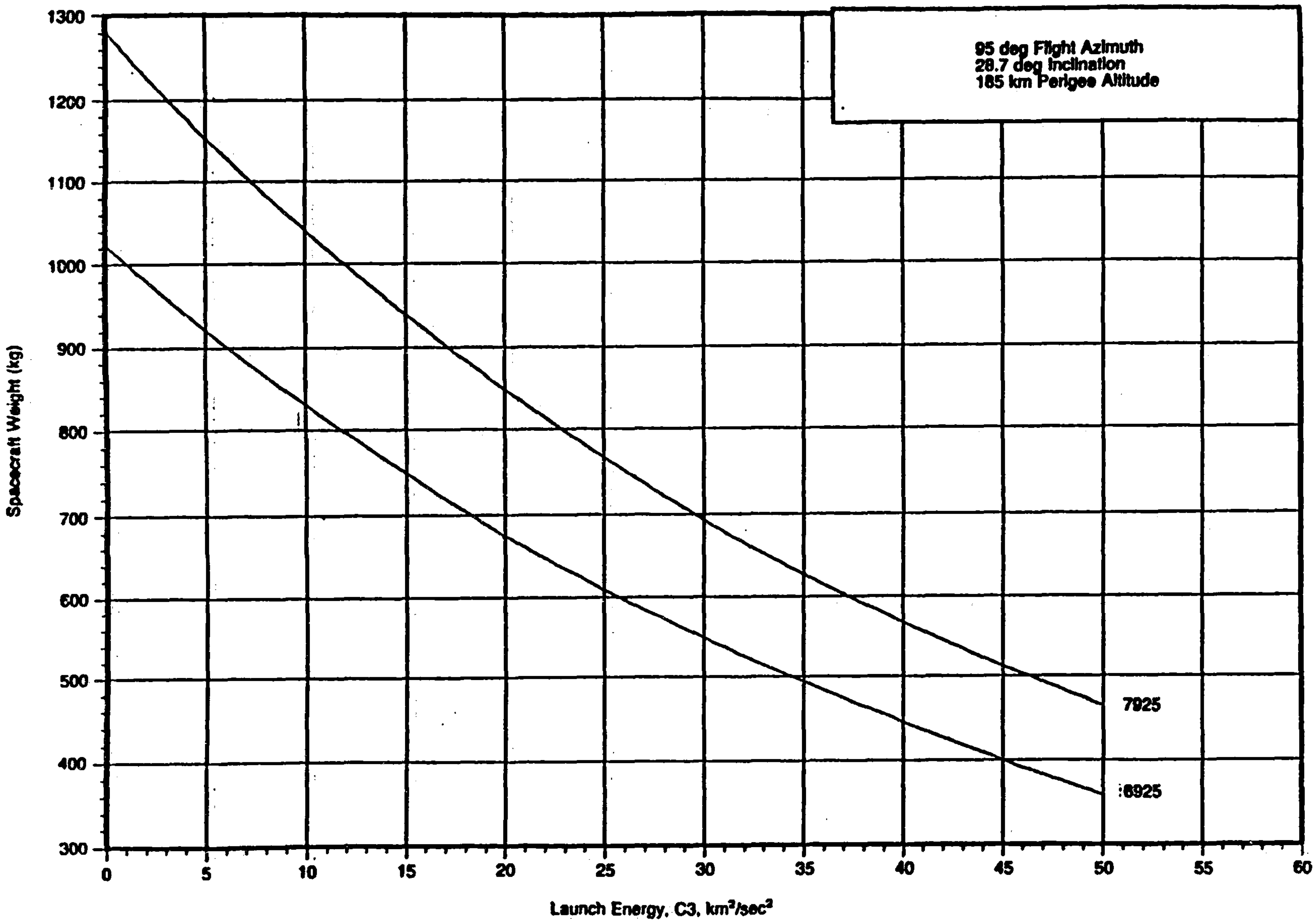


Figure 2-18. Three-Stage Planetary Mission Capability (Metric Units) – ESMC

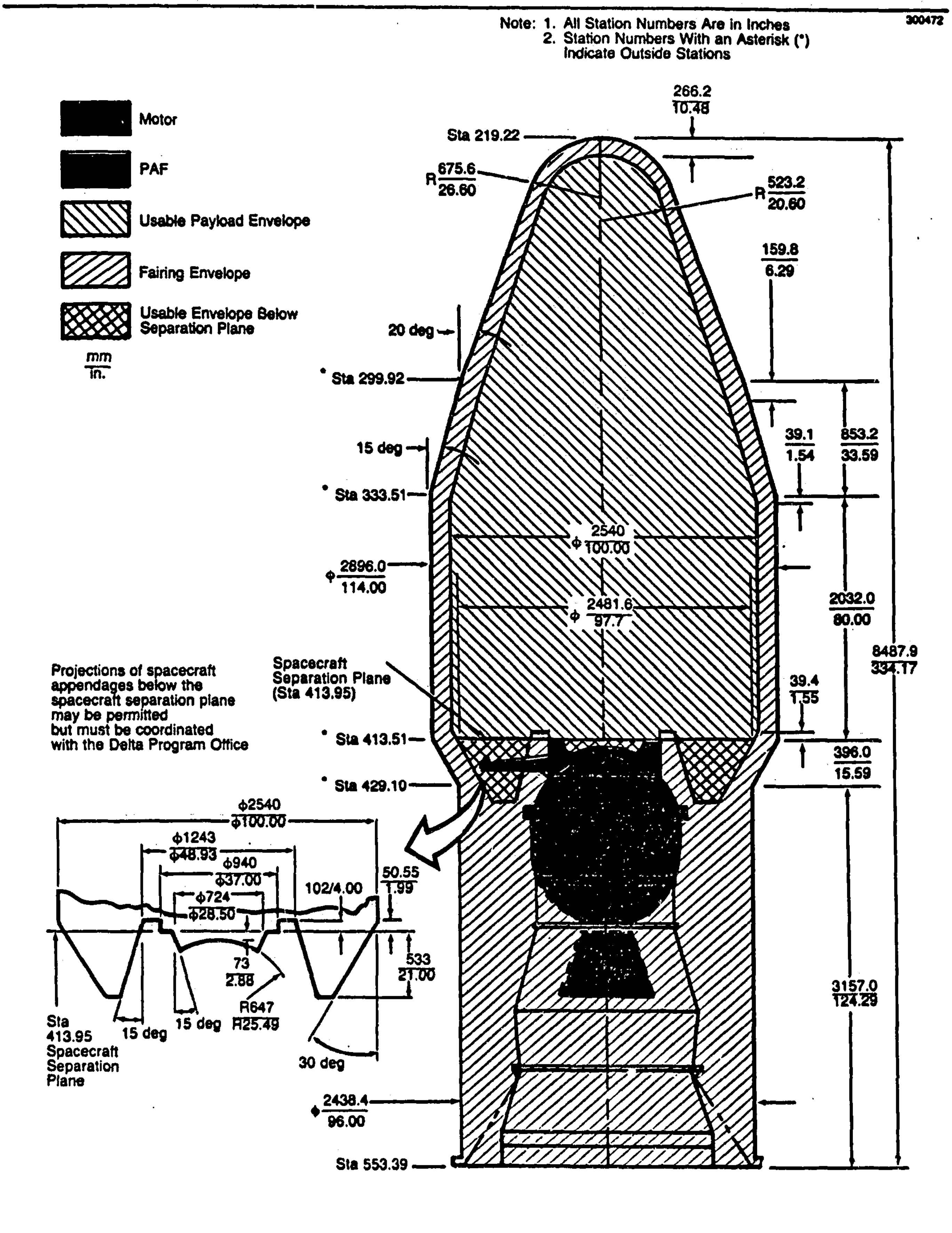


Figure 3-3. Spacecraft Envelope, Star 48B Configuration (3712 PAF)

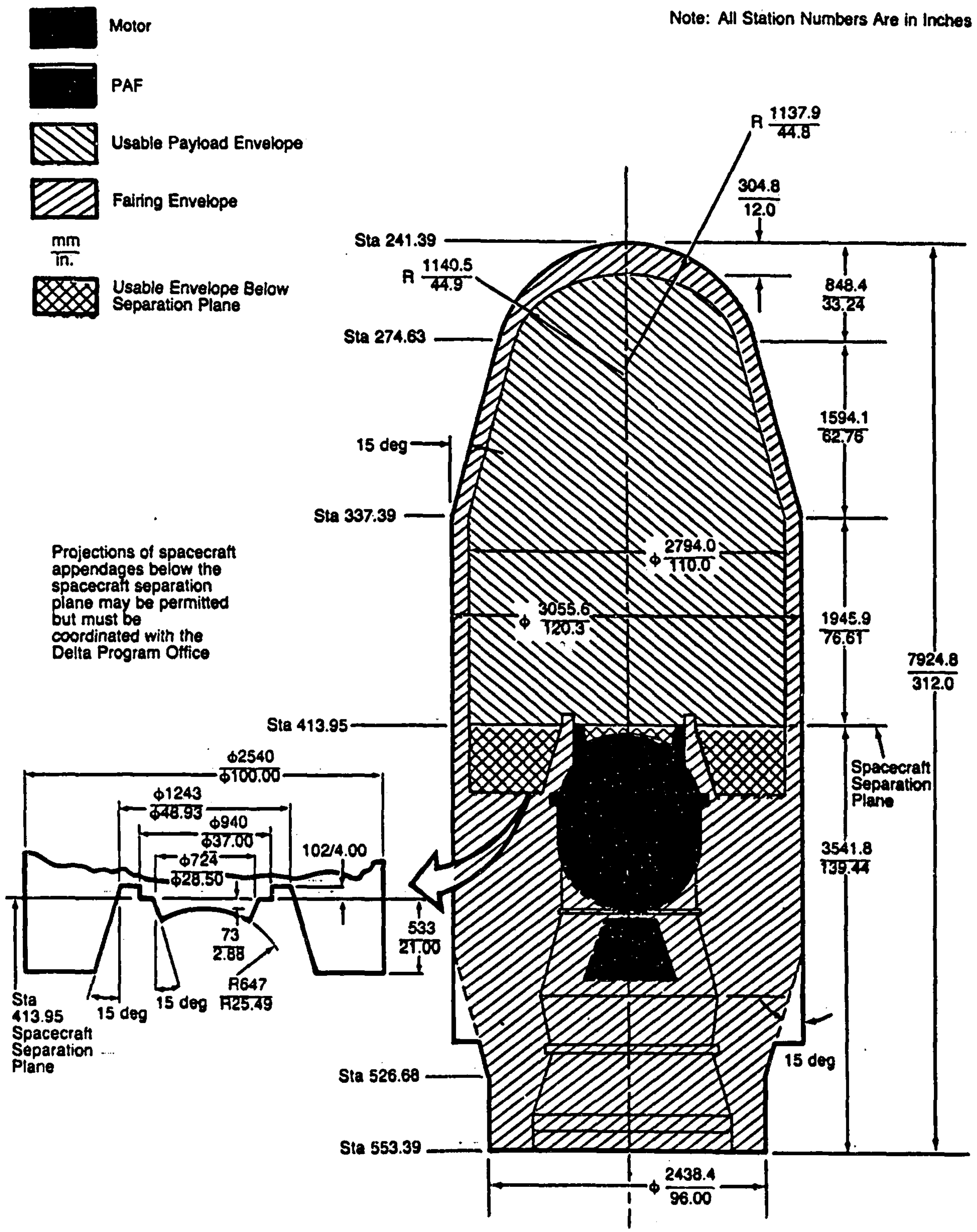


Figure 3-7. Spacecraft Envelope, Three-Stage Configuration, 10-ft (3.0 m) Dia Fairing

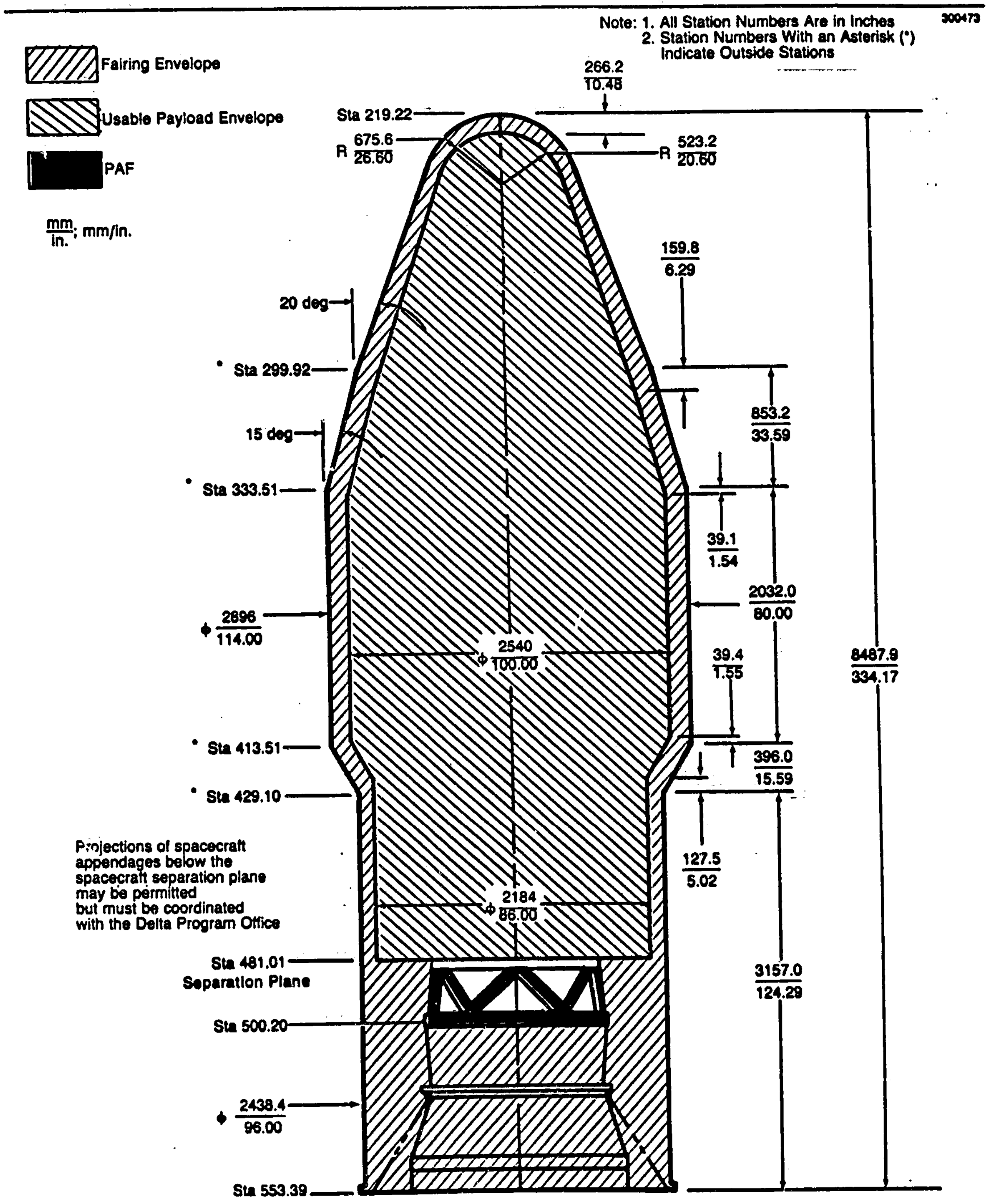


Figure 3-4. Spacecraft Envelope, Two-Stage Configuration (6019 PAF)

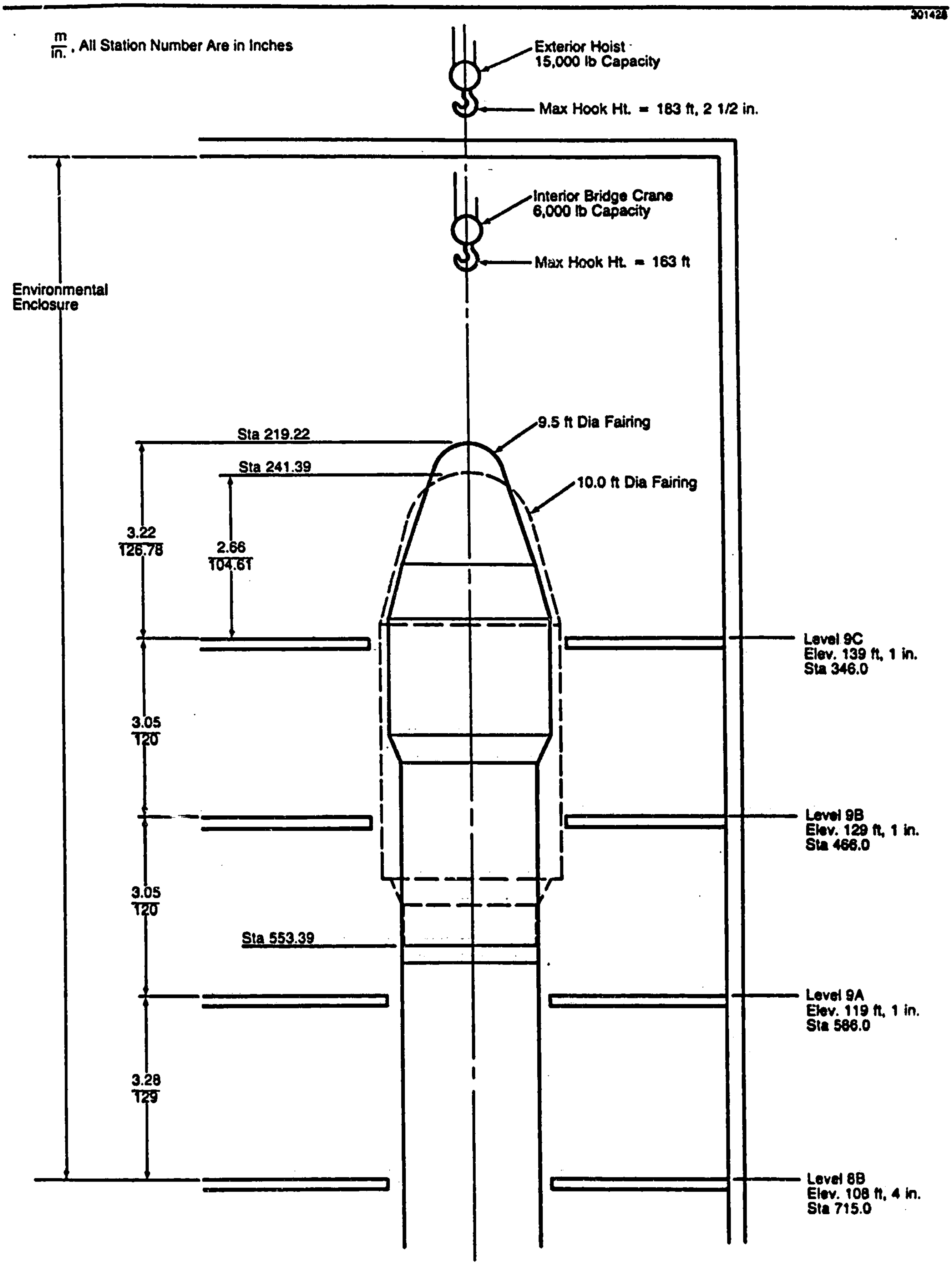


Figure 6-39. Environmental Enclosure Work Levels

300557

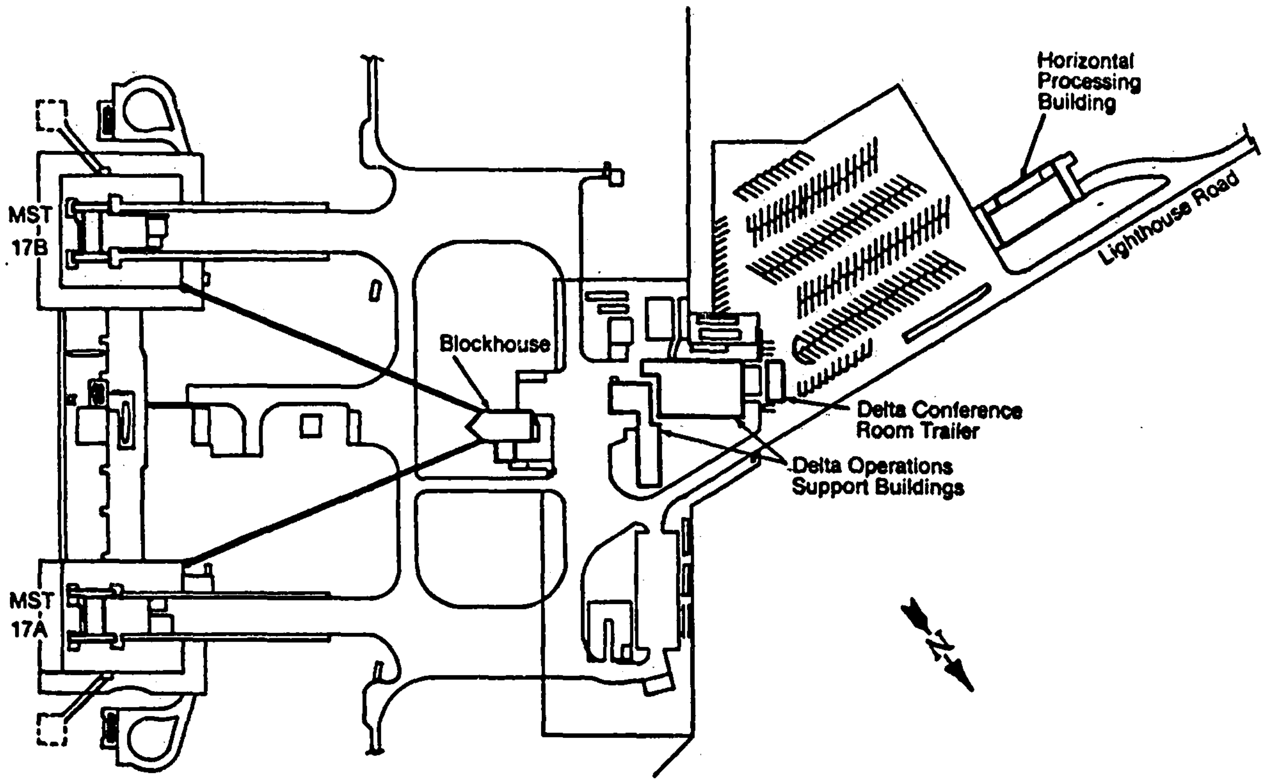


Figure 6-37. SLC-17, CCAFS

300558

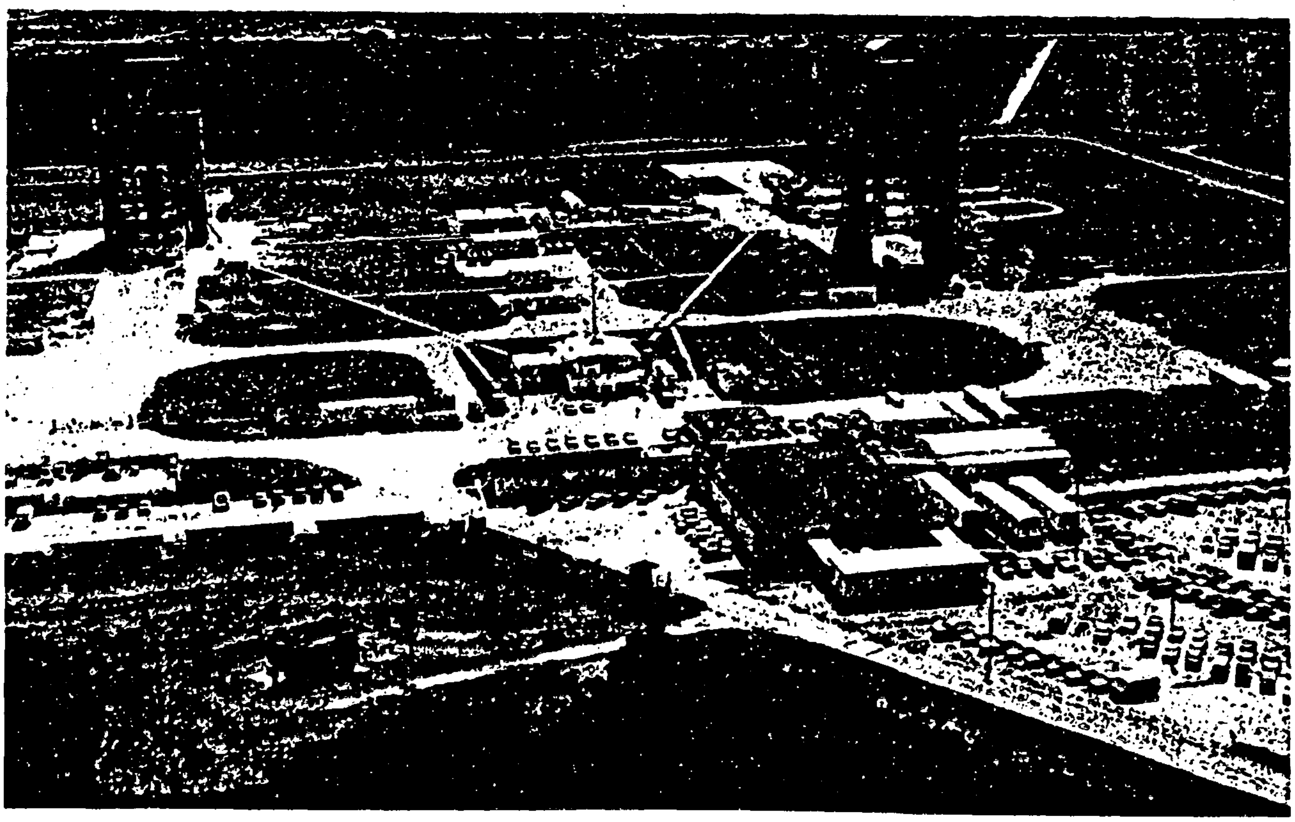


Figure 6-38. SLC-17 – Aerial View

DAC94926

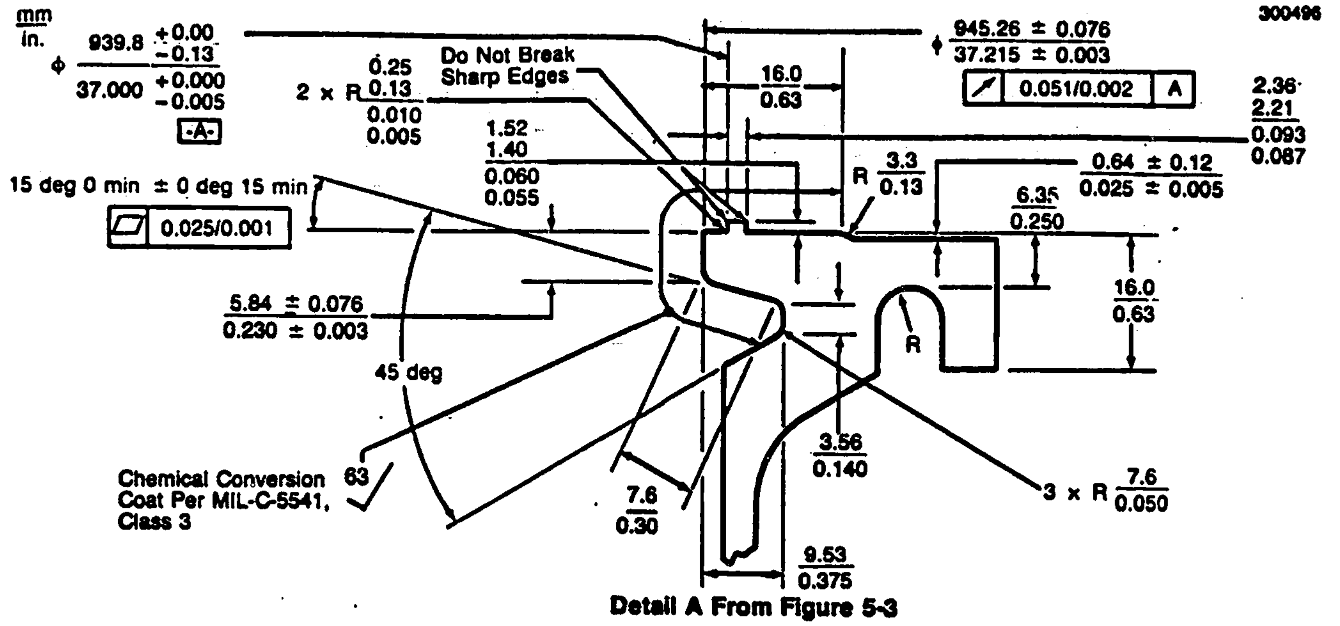


Figure 5-4. 3712A PAF Detailed Dimensions

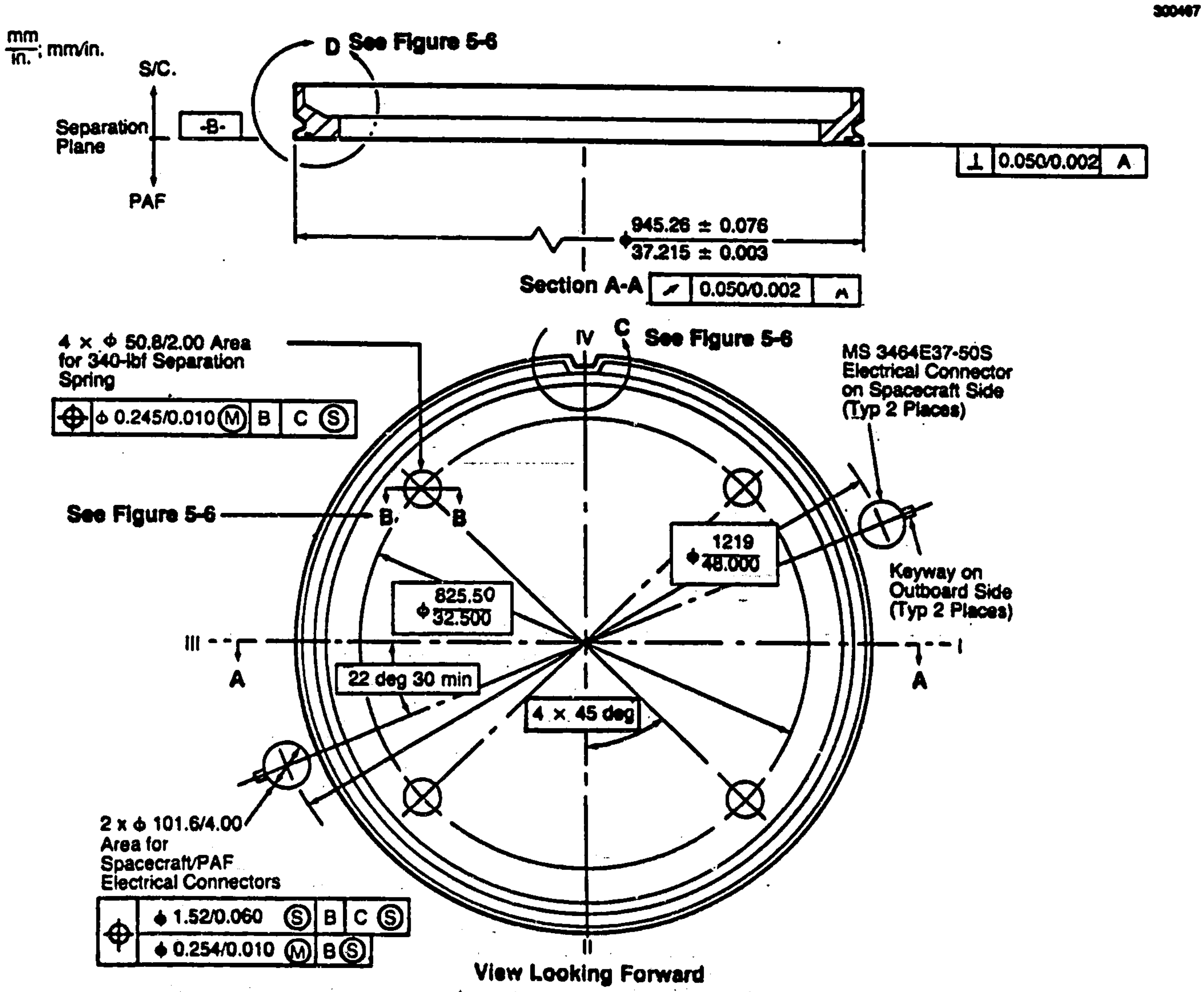


Figure 5-5. 3712A PAF Spacecraft Interface Dimensional Constraints (View A-A)